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Issued March 25, 1907.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 179,

A. C. TRUE, Director.

COOPER MEDICAL COLLEGE

SMALL RESERVOIRS

IN

WYOMING, MONTANA, AND SOUTH DAKOTA.

BY

F. C. HERRMANN,

Irrigation Engineer, Irrigation and Drainage Investigations, Office of Experiment Stations.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1907.

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NOTE.—Publications marked with an asterisk (*) are not available for distribution.

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*Bul. 105. Irrigation in the United States. Testimony of Elwood Mead, irrigation expert in charge, before the United States Industrial Commission, June 11 and 12, 1901. Pp. 47.

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Bul. 130. Egyptian Irrigation. By Clarence T. Johnston. Pp. 100.

Bul. 131. Plans of Structures in use on Irrigation Canals in the United States, from drawings exhibited by the Office of Experiment Stations at Paris, in 1900, and at Buffalo, in 1901, prepared under the direction of Elwood Mead, chief. Pp. 51.

[Continued on third page of cover.]

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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 179

A. C. TRUE, Director.

SMALL RESERVOIRS

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Irrigation Engineer, Irrigation and Drainage Investigations, Office of Experiment Stations.

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1907.

THE OFFICE OF EXPERIMENT STATIONS.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., December 3, 1906.

SIR: I have the honor to transmit herewith a report on small reservoirs, prepared under the direction of Elwood Mead, chief of Irrigation and Drainage Investigations, by F. C. Herrmann, irrigation engineer, of the Irrigation and Drainage Investigations of this Office.

The profitable use of a very large part of the arid and semiarid regions of the United States depends upon the storage and use of storm water falling on these lands. In this report Mr. Herrmann has described a considerable number of reservoirs which are now in use, discussing the conditions which are necessary to make storage possible, the proper construction and maintenance of reservoirs, and the use to which the water has been put. The plains section covered by the report is typical of the region where the greater part of the land must be used without irrigation, either for dry farming or for grazing, and only small areas watered. These small irrigated areas intensively cultivated will supply fruit and vegetables for household use, and hay and grain for the feeding of stock during winter storms or prolonged droughts. Range losses alone where no winter feed is supplied are estimated at 10 per cent.

In order that the information collected by Mr. Herrmann may be made available for others wishing to settle in the grazing regions, it is recommended that this report be published as a bulletin of this Office.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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SMALL RESERVOIRS IN WYOMING, MONTANA, AND SOUTH DAKOTA.

INTRODUCTION.

Development in the arid West in recent years has proceeded with enormous strides, due almost entirely to irrigation, the water applied to the land being for the most part taken directly from running streams. However, as this development has increased, the amount of available water from streams during the normal irrigation period has decreased, until in order that development may continue it is necessary to augment the normal flow of the streams. On many millions of acres of this arid empire we find streams that are torrential in character, being dry for the greater part of the year and running only at short intervals during the stormy season. To provide additional water in the one case and to conserve it in the other, recourse must be had to storage, which is also necessary to beneficially reuse water wasted upon application to the soil.

Storage reservoirs may be divided into three general classes: (1) Very large ones, involving the expenditure of enormous sums of money, which are usually constructed by the National Government or under the so-called Carey Act to reclaim vast areas; (2) moderately large reservoirs wherein the expenditures and area reclaimed are not so large as in the first class, which are constructed for the most part by private companies or associations of landowners; and (3) small reservoirs, the cost of which is within the means of the individual farmer or settler and which are constructed for the purpose of reclaiming comparatively small areas usually farmed in conjunction with unirrigated lands or range pasture, or to increase the flow in a canal during the critical period, providing against failure of crops from lack of late irrigation.

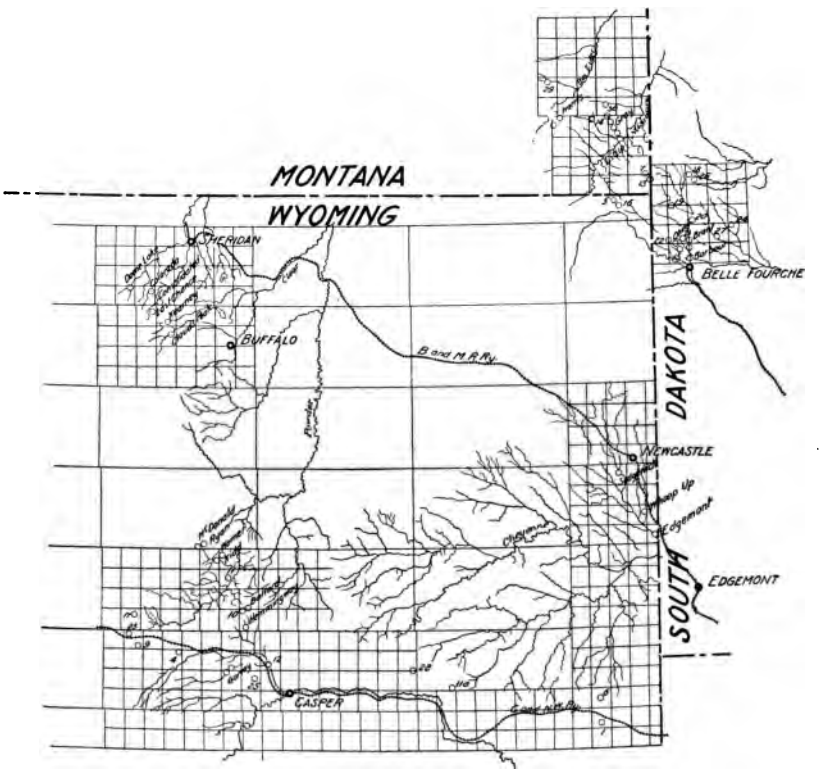
The reservoirs in the first class are rarely, if ever, constructed without elaborate preliminary investigation and ample engineering supervision. To a smaller degree this is also true of those in the second class, though there have been constructed a number of such structures over which there was no engineering supervision. Reservoirs in the third class, however, are very rarely constructed under even the most

limited engineering supervision or advice. In most of the arid States, however, the laws require that prior to construction a map showing the perimeter of reservoir, plan of dam, and land to be irrigated be filed with the proper State authorities. It is customary for this map to be hastily prepared by the nearest surveyor, whose greatest effort is to make the survey and map with the least possible expense. The plan of the dam is usually an afterthought, a sketch of a cross section being added to the map simply to comply with the letter of the law. It is needless to say that no investigation is made or careful consideration given to the preparation of these plans.

One reason, of course, for this lack of skillful investigation and supervision of construction is its very large cost in porportion to the entire cost of the structure, for it is usually a long distance from the reservoir site to the location of an engineer of the necessary experience and standing, and aside from the time devoted to actual work, much time is consumed in going to and returning from the work, all of which make this cost abnormal. Another, and often the real reason, is that the construction of a small dam is considered, by those who have not had experience in that line, an easy task in which no engineering advice is necessary. That this is not always true is evidenced by the very large number of failures in small reservoirs, though, as only a comparatively small quantity of water is impounded, usually no damage is done by these breaks other than to the structure itself. However, the loss of water that has been hoarded for months is a very serious matter to the farmer and more than likely results in a total failure of his crop.

A large number of small reservoirs are being constructed for the purpose of settlement on the public domain under the so-called desert-land act. The settlers can illy withstand losses and consequent discouragement, and very few of them can afford to pay for professional advice. Being in a very thinly settled district, they can not profit by the experience of their neighbors and they have no knowledge of the success or failure of similar ventures at other points. There has been much said of a derogatory nature regarding the settlers under the desert-land act, but the observation of the writer, during a careful investigation of the territory treated of in this bulletin, is that as a rule they are in deadly earnest in their efforts to reclaim the lands, that the cost is usually in the neighborhood of $10 per acre instead of $4.25 as required by the Government, and that during the period of reclamation they lead a life of great hardship and self-denial.

The purpose of this bulletin is to provide for those contemplating the construction of reservoirs a fund of information regarding the reservoirs already built, and by discussing their construction and the problems connected therewith to suggest to the settlers in the arid region the best methods to employ in carrying out like projects.



MAP SHOWING LOCATION OF RESERVOIRS DISCUSSED.

The investigation to gather the data for this publication was made in Wyoming, South Dakota, and Montana, where much has been done in the development of small water supplies to furnish water for stock and domestic purposes and to reclaim land far beyond the reach of any extensive irrigation system, as well as to increase the efficiency of irrigation systems by small storage. (See map, Pl. I.)

The investigation began with a visit to the reservoirs in the Big Horn Mountains west of Sheridan and Buffalo, in northern Wyoming, where data were gathered relative to the storage of water for irrigation purposes, after which an extended trip was made through western South Dakota, northeastern Wyoming, and southeastern Montana, starting with Bellefourche as the southern limit, and in central Wyoming, northwesterly and westerly from Casper. Lastly, a visit was made to the small reservoirs lying westerly from New Castle, Wyo., and Edgemont, S. Dak.

The trip to the reservoirs in the Big Horn Mountains was made in company with Mr. C. T. Johnston, State engineer of Wyoming, to whom acknowledgment and thanks are due for aid rendered in gathering data in both field and office. On the trips out of Bellefourche and Casper the many reservoirs constructed by the Chicago and Northwestern Railway Company were used as a nucleus for the work on small reservoirs on the prairies. Acknowledgment is due Mr. A. A. Schenk, engineer of the western lines of the Chicago and Northwestern Railway Company, for courtesy and aid during the investigation, and to Mr. T. K. Peck, resident engineer of the Black Hills division of the same company, with whom the trips from Bellefourche and Casper were made, who pointed out the way, through many days of riding, over a vast arid empire devoid of roads and where often only one cabin was seen during an entire day, furnishing at all times information of great value concerning the physical condition of the country and the local progress and problems of the construction of small reservoirs. Acknowledgment is also due Mr. W. S. Palmer, section director of the United States Weather Bureau for Wyoming, for aid and courtesy in furnishing data relative to intensity of storms in Wyoming. Acknowledgment would be incomplete without including the many settlers and farmers who aided in every way in their power and who eagerly gave us information and showed deep appreciation of the efforts being made by this Office in their behalf.

TYPES OF RESERVOIRS UNDER CONSIDERATION.

The reservoirs within the zone of the investigation divide themselves geographically into two groups—those located in the mountainous region and those located on the open prairie. Aside from being constructed for the purpose of impounding water, these two groups have very little in common. They differ greatly in physical

conditions and environments, in the availability of water supply, in proximity to place of use, in problems of construction and maintenance, in character of tributary catchment area, and in materials available for construction and consequent types of dams used. The two groups, therefore, will be considered separately.

RESERVOIRS IN BIG HORN MOUNTAINS.

The Big Horn Mountains extend nearly north and south through the central part of the northerly half of Wyoming. Their crest is, for the most part, about 10,000 feet above sea level and forms the divide between Big Horn River on the west and Powder and Tongue rivers on the east. Their slopes are, for a large part, well wooded, principally with lodgepole pine, and have numerous snow-fed streams leading into the valleys. Having been subjected to glacial action, these mountains abound in excellent reservoir sites, both large and small, particularly between the elevations of 6,000 and 9,000 feet. At the foot of the easterly slopes of these mountains lie the towns of Sheridan and Buffalo, surrounded by irrigated areas aggregating about 170,000 acres, at an average altitude of 4,000 feet.

Being at a moderate elevation, well protected by the mountains, and supplied with water for irrigation, apples, cherries, plums, berries, alfalfa, grain, and vegetables are raised without difficulty and give handsome returns. The water for irrigation is taken principally from Tongue River, Big Goose, Little Goose, Piney, Clear, and Crazy Woman creeks and their tributaries, and these streams at first furnished abundant water for all purposes; but as the country developed the demand became greatly in excess of the supply. This deficiency applied particularly to late irrigation, as the head gates of ditches with late water rights are often closed for the season at a time when water for irrigation is greatly needed. The solution was storing the flood waters, which had been allowed to pass unused, often augmenting the destruction caused from floods in the rivers which they enter. During the past ten years sufficient water has been stored to provide for 10,000 acres, at an expense of upward of $40,000. A careful analysis of the flow and topography of the various streams above mentioned indicates that sufficient water is available for storage to increase the irrigated area to one half million acres, and that there is ample opportunity to store it. The advent of the sugar-beet industry into this district has already caused great activity in the construction of storage reservoirs, and we may look forward to the creation here of a system of storage reservoirs of exceptional efficiency.

The cost of storage so far has not exceeded $5 per acre of land irrigated. Of course those sites affording the cheapest storage have already been utilized and the cost for future storage will be much

greater. Making the liberal estimate of $15 per acre, the cost of placing under irrigation the additional 330,000 acres to make one-half million acres would be about $5,000,000. Of the total irrigated area, about one-tenth, or 50,000 acres, could be continuously devoted to sugar-beet culture, which, with beets at $5 per ton at the factory and with an average yield of 12 tons per acre and an average cost of production of $40 per acre, would earn $20 per acre per year, or a total of $1,000,000 per year. From this it is seen that in six or seven years the crop of sugar beets alone would pay the entire cost of storage, including interest on the investment.

DOME LAKE RESERVOIR.

Dome Lake is located in the upper reaches of the West Fork of Big Goose Creek, 20 miles southwest from Sheridan, and at an elevation of 8,700 feet above sea level. The site is divided into two distinct parts, of about 90 acres each, connected by a narrow stream, the upper of which is a natural lake, while the lower is a meadow subject to inundation by high water, the whole almost completely hemmed in by low, narrow glacial ridges. The lake is a very beautiful spot and has been utilized for many years as the summer home of a club. Irrigation progress, however, has demanded that this excellent site be used for the storage of water, and permission has been granted a company to raise the level of the lake not to exceed 3 feet by constructing a low dam at the "narrows" and to completely submerge the meadow by constructing at the lower end a dam 29 feet high. It is to be regretted that the owners saw fit to limit the height to which the lake level should be raised, as there is ample opportunity, at a small cost, to more than double the capacity of the reservoir without doing any material damage, and the additional stored water would be of great value to agricultural interests in the valleys below.

The reservoir has a catchment area of about 40 square miles, well wooded up to timber line, above which are mainly bare granite cliffs leading to the crest, upon which are many lofty peaks perpetually covered with snow. It is estimated that this catchment area is capable of furnishing annually upward of 5,000 acre-feet.

It is the purpose of the company undertaking this work to construct the lower reservoir first, raising the water surface of Dome Lake proper at a later date. Construction of the lower reservoir was begun last year and considerable progress made. With a dam 29 feet high and 1,000 feet long, a reservoir with a water surface of 91 acres and a capacity of 1,300 acre-feet will be created. The water stored will be turned into Big Goose Creek, from which it will be diverted and used for late irrigation of the lower-lying lands. As yet it has not been attached to any certain tract of land, as the Wyoming reservoir law provides that stored water may be disposed of under any agreements

satisfactory to the parties concerned. This provision regarding stored water is a departure from the general spirit of the Wyoming irrigation laws and may result in extortion in times of scarcity of water, which the Wyoming laws were especially designed to prevent.

A careful preliminary examination of the site of the lower Dome Lake Reservoir was made by an engineer prior to beginning the work, and construction so far has been under his direction. As the entire site is in a glacial deposit, the prospect for a good foundation was not encouraging. However, the examination developed a well-defined underlying stratum of clay at a satisfactory depth, which, together with an adjacent body of good puddling material and ample earth in the vicinity for construction, determined the type of dam to be used. The dam is to be of earth and rock with a central puddle core wall reaching down to the impervious stratum of underlying clay. Its dimensions are: Top width, 15 feet; water slope, 1 on 3; outer slope, 1 on 1½; and a maximum height of 29 feet, with the high-water line 4 feet below the top of the dam. The puddle wall has a top width of 5 feet and a bottom width of 10 feet. The water slope is to be rip-

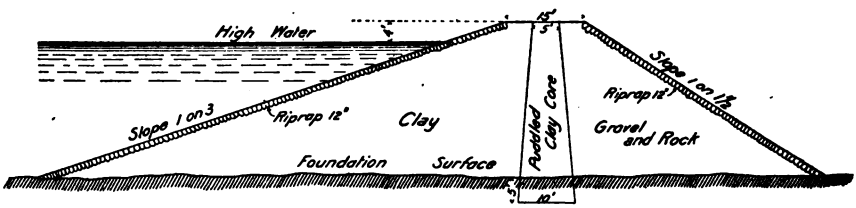


FIG. 1.—Section of dam of Dome Lake Reservoir, showing arrangement of material.

rapped with large bowlders, of which there is an abundant supply near at hand. It is purposed to arrange the material in the dam in the manner shown in figure 1, placing the selected impervious material between the core wall and the upstream face to secure water-tightness, and the gravel and rocks below the core wall to insure drainage. In this manner it is hoped to prevent saturation of the body of the dam and seepage beneath it. On account of the rather unfavorable character of the foundation, an earthen dam with a broad base, distributing its weight over a large area, is undoubtedly the best type to be chosen, and though the present tendency of engineers is to avoid clay puddle cores, it would be difficult in this case to provide otherwise against loss beneath the dam. The danger of settlement would certainly preclude the use of a concrete core wall. The riprapping of bowlders on the water slope of the dam is to be placed directly on the earth, and as there are seldom very high winds in this vicinity, owing to its protection by surrounding hills, it would appear that this will suffice to resist the action of the waves, though it doubtless would be a wise provision to insert a layer of gravel or broken stone between

the earth surface and the riprapping. Though great care was necessary in preparing the foundation, by far the greatest difficulty in connection with this work is the great distance supplies, tools, materials, and machinery must be hauled, together with the short working season available at the site. All supplies, etc., must be hauled from Sheridan, the nearest railroad town, over 25 miles of poor road, making a total rise of 5,000 feet, and the season within which work is permissible begins about June 15 and ends September 15, an interval of only three months, or about one-fourth the time it is customary to put on work. On account of the high altitude men can not work nearly so well as at lower altitudes, so that when the work is complete we are to expect the cost to be very high comparatively.

The work of preparing the foundation and building the lower part of the puddle wall and dam was begun in 1905 and carried on satisfactorily during the remainder of the season, leaving the dam in a condition to resist the spring freshets. Upon the opening of the working season, construction will be carried forward vigorously, probably to completion at the end of the favorable weather.

COLORADO RESERVOIRS.

These, when complete, will be seven in number, and form a chain separated by short stretches of canals which lead the water of Cross Creek into Little Goose Creek, crossing en route a divide nearly 300 feet high. These reservoir sites are all located within two sections of land about 6 miles east of Dome Lake, and provide storage for the flood waters of Cross Creek and secure a right of way between Cross and Little Goose creeks. They lie along the line of the Peralta Ditch, which has a much earlier water right, and also carries the water of Cross Creek into Little Goose Creek. So far as could be ascertained, the Peralta Ditch has no interest in the water stored in the Colorado reservoirs. The stored water is emptied into Little Goose Creek and allowed to run in the natural channel to a place north of the settlement of Big Horn, where it is diverted and used by Colorado Colony.

It is claimed that when this entire chain of reservoirs is completed late irrigation will be provided for 5,000 acres of land upon which it would otherwise be possible to raise only those crops which would mature by early irrigation alone, for the head gate of the Colorado Colony is usually closed to the natural flow of the stream some time between the 1st and 15th of July.

These reservoirs being located away from the main streams of either Cross or Little Goose creeks, and each having practically no tributary watershed, no wasteways are necessary other than those used to draw the water from the various reservoirs and to permit the flow of sufficient water for the use of the Peralta Ditch. The

reservoirs vary in area from about 2 to 30 acres, with a total of 75 acres, and when completed the series will have a combined storage capacity of about 500 acre-feet. From this it will appear that unless this storm water is to be augmented by the natural flow of the stream, late irrigation for 5,000 acres will be impossible. If great economy be exercised, the extreme limit would be 750 acres.

The geological formation at these sites is not unlike that at Dome Lake, though apparently in every case the foundation is not to be considered as needing such careful treatment as was required at Dome Lake. There is ample earth and rock within easy reach, though very little, if any, clay. Where dams for some of these reservoirs have been constructed recently no effort was made to select or use good material nor to secure good workmanship, but the coarse sand near at hand was scraped into heaps without any care upon foundations of sod-covered peat, without the precaution of even removing the sod, and leaving slopes as steep as the angle of repose of the sand, usually 1 on 1½, notwithstanding that the plans filed in the State engineer's office specify a water slope of 1 on 3

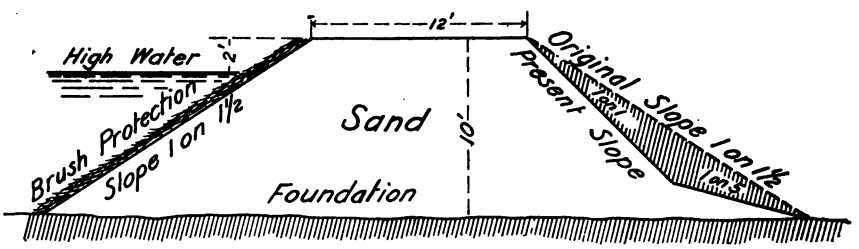


FIG. 2.—Change in outer slope of Colorado Dam, due to saturation.

and outer slope of 1 on 2. In some cases the water slopes were paved with bowlders, and in others brush thrown upon the slope in a haphazard way was used for protection against waves, which, owing to the fortunate protection of nature against winds, are not of consequence. The dams all have a maximum height of about 10 feet, with 8 feet of water behind them. No attempt was made to secure water-tightness, and as a result the dams, although constructed but one year, are thoroughly saturated, leak abnormally, and are beginning to change shape on the lower slope, as shown in figure 2. In fact, they are so badly saturated that one attempting to walk up the outer slope will sink knee deep in wet sand. That these dams have not already failed is due to their small height and the lack of waves and wind.

The outlets are ordinary 10-inch or 12-inch lap-welded pipes, provided with gates at the upper or inner ends. Each gate is operated by a wheel and a stem, which are protected from floating logs or stumps by a fender made of logs, as shown in Plate II, figure 1.

No provision has been made against silting. Of course, as those of the reservoirs that are complete have been in operation but one

FIG. 1.—ONE OF THE COLORADO RESERVOIRS, SHOWING HOMEMADE GATE FENDER.

FIG. 2.—LAST CHANCE RESERVOIR DAM, SHOWING RIPRAPPING FOR WAVE PROTECTION.

year, no appreciable amount of silt has been deposited in the floor of the reservoir, though, with connecting canals whose grades vary to as high as 300 feet per mile, great erosion and consequent silting are to be expected where the land consists of earth and bowlders, as it does in this vicinity. In fact, in the lowest and largest of these reservoirs quite a sand bar has already been formed where the water enters.

The Colorado Colony has an excellent opportunity to make itself secure against drought by storage in this chain of lakes, though greater care is certainly to be desired in locating, designing, and constructing the dams.

CONSOLIDATED RESERVOIR.

The Consolidated Reservoir is also located on the upper reaches of Little Goose Creek, and was built in 1899 through the cooperation of several landowners in the Goose Creek Valley who own about 500 acres. This was truly a cooperative affair, for each man interested worked with his own horses in building the dam, which ever since has been operated and maintained in partnership.

The dam is an earthen structure having a crest width of 9 feet, a maximum height of 18 feet, a water slope of 1 on 2½, and an outer slope of 1 on 1½. There is a considerable catchment area tributary to the reservoir, but on account of the inaccuracy of available maps an estimate of this could not be made. A wasteway 25 feet wide and 3 feet deep was constructed around the westerly end of the dam. This was made of boards and has evidence of having carried waste water to about one-half its capacity, which, assuming a velocity of 3 feet per second, would give a waste of about 100 cubic feet per second. This wasteway, though it is allowed to spill quite close to the toe of the slope of the dam, has so far done no material damage. For safety, however, waste water should always be discharged at a distance from the dam.

Ordinary earth, with perhaps a preponderance of sand, which was close at hand, was used in construction. No effort was made to introduce a core wall of any sort, though, as practically no settlement has occurred since construction, care was evidently taken in placing the material, and there is no indication below the dam that any leakage has occurred. The work was done with slip scrapers, and doubtless the compactness of the mass is due to the constant tramping of the horses and the small amount of earth deposited at each load, as well as the careful preparation of the foundation to insure a bond between it and the lower course of the dam. The water slope of the dam was riprapped with large bowlders, which are still in place. The margin of the reservoir being densely wooded affords a very large degree of protection from waves.

The outlet is a wooden box 12 inches square placed at the lowest point in the dam, the gate being placed in a wooden well in its center. As the working period at all the reservoirs in the Big Horn Mountains is short, initial construction should be of such a character as to avoid the necessity of repairs, and a wooden box outlet should never have been used in the dam. Though cheap and easy to construct, it will be very expensive and annoying in the long run.

LAST CHANCE RESERVOIR.

The Last Chance Reservoir is located about 5 miles above the Consolidated Reservoir. It was constructed at about the same time, as a cooperative venture, and the stored water is used in late irrigations on approximately 500 acres in the valley of Little Goose Creek. In general appearance, workmanship, and capacity it excels the Consolidated Reservoir. The reservoir is off the main stream and is fed by Rapid Creek, a tributary of Big Goose Creek, through a ditch several miles long constructed on the steep hillside.

The dam is an earthen structure having a maximum height of 12 feet, a length of 500 feet, a top width of 10 feet, a water slope of 1 on 3, and an outside slope of 1 on 1½. The material was moved with slip scrapers, and judging from the result was thoroughly packed by the tramping of the horses, for there are no signs of seepage through the dam. This is the more surprising because it is not a material from which such good results might be expected, as sand and small bowlders are present in rather larger quantities than desirable and the foundation upon which the dam was built is composed largely of bowlders and earth. The water slope was carefully paved with large bowlders, as, on account of the long reach of the wind, waves of considerable size were anticipated. The bowlders were bedded in the slope of the earth and have so far shown no signs of weakness. Plate II, figure 2, shows the dam and paved slope. The water surface in the reservoir stands at the bottom of the wasteway, which is a wooden box 10 feet wide and 3 feet high, at the eastern extremity of the dam. The waste water discharges on a large mass of bowlders and has thus far done no harm. Although the reservoir is not in the main stream bed it was deemed best to provide a wasteway for storm-water run-off of the rather small tributary catchment area. That this was a wise provision is evidenced by the fact that water marks indicate water to the depth of at least 12 inches having passed through the wasteway.

The water is drawn off through lap-welded pipe which pierces the dam near the bottom at its highest place and follows a natural watercourse tributary to Little Goose Creek, after which it flows down that creek to the headgate of the Last Chance Canal. As nearly as could be ascertained, no special effort was made in either the Consolidated

or Last Chance reservoirs to secure a good bond between the foundation and the dam, nor to prevent seepage along the outlets, yet in neither case has there been any trouble from this source.

CLOUDS PEAK RESERVOIR.

Clouds Peak Reservoir is being constructed by utilizing the lake of the same name, which is one of a group of lakes located some 20 miles west of the town of Buffalo, in the headwaters of Piney Creek, and at an elevation of about 9,000 feet. Just west of it is Clouds Peak, one of the loftiest mountains in Wyoming, the glacier upon whose eastern slope supplies a number of streams on the eastern slope of the Big Horn Mountains. Around the lake there is a narrow fringe of timber, above and behind which stand out immense walls and cliffs of bare granite, a large part of which are covered perpetually with a mantle of snow. It is the judgment of those who have carefully watched the discharge from Piney Creek that the catchment area above Clouds Peak Lake is capable of furnishing sufficient water to fill the completed reservoir many times over, and they look forward to the time when a number

FIG. 3.—Section of Clouds Peak Reservoir, showing proposed disposition of material.

of the other lakes and meadows that occur in that neighborhood will be utilized for the storage of water. The construction of this reservoir is being undertaken by a company of 6 landowners living in the neighborhood of Buffalo. Their plan is to build a dam about 15 feet high across the outlet of the lake and cut an outlet some 10 feet below the rim of the lake. In this manner the water level of the lake can be raised 10 feet and lowered 10 feet, making an available depth of 20 feet. The lake is about 1 mile long, averages from one-fourth to one-third mile wide, and has an area of about 170 acres, and the capacity of the reservoir above the outlet will be in the neighborhood of 3,000 acre-feet.

Clouds Peak Lake was undoubtedly caused by glacial action. It differs from other sites in that there is some cementing material among the bowlders at the lower extremity of the lake, forming a rim of very hard conglomerate, an excellent foundation for a dam.

The type of dam first chosen was a combination of earth and loose rock, there being necessary for a dam 20 feet high about 15,000 cubic yards of earth and 6,000 cubic yards of loose rock. The disposition of these materials was to be as shown in figure 3, whi[illegible]very well

where there is an ample supply of both rock and earth, but earth at this site is exceedingly scarce and is lodged in the interstices between bowlders, making it an almost hopeless task to secure a scraperful of earth per square mile.

Before very much work had been done on the dam itself the plan of the dam was changed to one of the rock fill type, as ample material for this class of construction is close at hand and a great deal of cement will not be needed to secure imperviousness. The cross section and arrangement of this dam are shown in figure 4. The water slope is 1 on ½ and is provided with a skin of selected rock laid in cement mortar, which is carried down and carefully bonded to the underlying cemented conglomerate, thereby providing imperviousness and getting the benefit of the weight of the entire dam in resisting the pressure of the water. On account of the steepness of the water slope and the comparatively small height of the dam it is not anticipated that settlement in the body of the dam will result in serious injury to the impervious wall, and at most any settlement cracks that may occur

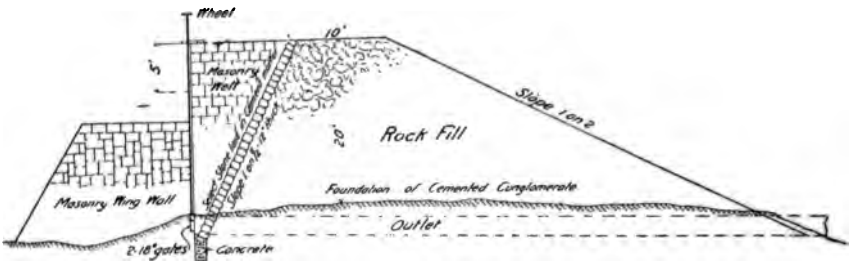


FIG. 4. Section of Clouds Peak Reservoir, showing disposition of material.

can be repaired easily when the water in the reservoir is low. The stones in the wall will occupy positions normal to the slope, which in itself will tend to withstand the tendency toward cracking. The slope of 1 on 2 on the outer slope is ample. It is planned to provide ample wasteway around the end of the dam, which will in no way interfere with the toe of same, the dam standing in no danger of being overtopped. The outlet passes through the cemented rim rock and, save for the walls and gate well, is not connected with the body of the dam.

Work was begun on the outlet first, in order to get the benefit of the water in the lake prior to the construction of the dam. The adverse conditions under which work must be carried on are even more pronounced than those at the Dome Lake Reservoir. It is a trifle higher than Dome Lake, making the working season, if anything, shorter and the atmospheric pressure less. On account of the nonexistence of roads, it is much more difficult of access, which increases the cost of supplies and materials for the work enormously.

So far work has been confined to cutting the outlet, installing two large iron gates, and constructing concrete masonry walls for the pro-

FIG. 1.—OUTLET OF CLOUDS PEAK RESERVOIR.

FIG. 2.—SECTION OF OUTLET DITCH OF CLOUDS PEAK RESERVOIR, SHOWING LINING OF DRY STONE WALL.

tection of the entrance to the gates, and a concrete well, by means of which the gates are operated. This gate with well and walls is shown in Plate III, figure 1. These gates, weighing several tons each, were taken from the railroad some 50 miles from the reservoir, and, on account of their weight and make, had to be hauled all the way intact, which precluded the use of pack animals. For the first 40 miles, or to the base of the Big Horn Mountains, no serious difficulties were encountered, but for the last 10 miles there was no road. By the use of a great many animals and ingenious methods for braking, these gates were hauled in a wagon over exceedingly steep mountains, through thick timber and brush, and over very rough gorges and canyons, the path taken being even now a difficult one for a man on horseback. The sacks of cement used in the concrete work were transported by pack animals at great expense. On account of the shortness of the working season, and the difficulty for men to work at such a high altitude, progress has not been rapid, though by the fall of 1905 the outlet was complete and the foundation of the dam was partially cleared. It was the intention to install derricks and a cableway as soon as the season of 1906 opened, and to carry on the remaining work with all possible speed.

The stored water is discharged into South Piney Creek, down which it travels for several miles, where it is taken into a ditch along a precipitous mountain side, carried across the divide between Piney and Rock creeks, and discharged into the latter. This ditch has a bottom width of 8 feet and a depth of 4 feet, is some 2 miles in length, and for a considerable portion of the distance is in a steep hillside of bowlders and earth. This has given considerable trouble, as the eddies created along the uphill bank wash the earth away from the bowlders, causing large slices of the hillside to slide into the ditch. Accidents of this sort caused damage, which in some cases it took weeks to repair, and because of their rather frequent recurrence it was decided to line the banks of the ditch through this treacherous ground with dry stone walls, carefully laid, and clear from any earth. It is believed that in this way fewer eddies will be created, and those which do occur will be harmless. When visited the ditch thus repaired had not been in use. Plate III, figure 2, shows a section of the reconstructed ditch. In the background of the view is a slide caused by eddies not yet removed.

On account of the adverse conditions, the cost of the work so far has been abnormally large, that of the concrete being estimated at upward of $12 per cubic yard, while the excavation for the outlet is placed at $2.50 per cubic yard, and the rock-lined ditch at 50 cents per linear foot. Altogether about $10,000 has been spent upon this work, which, when complete, is expected to furnish sufficient water to irrigate at least 1,000 acres, all of which lies along Rock Creek just west of the town of Buffalo.

KEARNEY LAKE RESERVOIR.

The conversion of Kearney Lake into a reservoir was an undertaking in many ways similar to the Clouds Peak enterprise. The two sites are at about the same elevation and only 5 miles apart, the one being situated on the North Fork of South PineyCreek and the other on the South Fork of South Piney Creek. In each case storage depended upon raising the surface of the water of a lake, the plans for the Kearney Lake Reservoir providing for raising the level about 40 feet. The reservoir is to have a water surface of about 150 acres and a capacity of 3,800 acre-feet. The character of its tributary catchment area is much the same as that of Clouds Peak Reservoir, but it is nearly twice as large. The dimensions of the dam are: Maximum height, 45 feet; top width, 10 feet; length, 700 feet; and both slopes, 1 on 1½, the inner slope being riprapped. The material called for is a mixture of earth and rock, the dam to be pierced with a 24-inch pipe.

The history of this reservoir is a most unfortunate one for the progress of storage in Wyoming. With such plans and with the very best of work success would have been very questionable. As nearly as could be ascertained the construction work was worse than the plans, with the result that long before the dam reached its intended height it failed, turning loose a large amount of stored water, which created havoc to settlers for some distance down stream. Regarding the cause for failure and the height of water in the reservoir at that time there is a vast difference of opinion among men who were present on the scene very soon after the disaster. It is stated by some that there occurred a sudden rise in the lake, due probably to a short storm of great intensity, which caused the dam to be overtopped. Others state that there could not have been a sudden rise in the lake, as there was no indication of a storm at that time, and that failure was due to very poor construction in both foundation and dam. To substantiate their statement regarding the sudden rise in the lake, they point to débris and refuse at various points within the reservoir site, lower in elevation than the top of the dam at that time, that during the break had evidently remained undisturbed, an impossibility had the surface of the water reached them. There is an opportunity to make an excellent reservoir of this lake, and, whatever the cause of failure may have been, steps should be taken without delay to remedy defects in both plan and construction in order that construction may proceed with certainty of success.

In collecting the data relative to the above-mentioned reservoirs it was practically impossible to obtain even approximate figures of cost, as so much has been done by the owners themselves at odd times, no record of the time being kept. Regarding the value of storage in the Big Horn Mountains, however, it is very conservatively estimated that the advance in land values, due entirely to the use of the flood

waters, has been 25 per cent. On land that has not the benefit of very early water rights and can therefore, without storage be irrigated only during the early spring, the crops raised must be limited to some of the small grains, giving the land a value of from $6 to $20 per acre, whereas if this same land be given the benefit of late irrigations by means of storage reservoirs a large variety of crops may be raised, including alfalfa, sugar beets, vegetables, fruit, and berries, increasing the value of the land $50 to $150 per acre. No sales of stored water have taken place in this section, making it impossible to determine the value of stored water in this way. A number of gentlemen well versed in local conditions gave it as their judgment that the value of the right to an acre-foot of stored water annually is at present from $15 to $25. It is contemplated that during the coming season at least five additional reservoirs will be constructed in the Big Horn Mountains.

It is to be hoped that, with the constant increase in the number of storage reservoirs throughout Wyoming, provision will be made that their construction be carefully inspected to avoid the recurrence of such disasters as the failure of the Kearney Lake dam. At the present time authority for such inspection is vested in the State engineer, but, as there are no funds available for this purpose, inspection is confined to what he personally can accomplish along this line. His duties are manifold, with the result that inspection gives way to other and more pressing matters. In Colorado such inspection is provided for.

Following is a tabulation of the principal features of the reservoirs above described:

Reservoirs in Big Horn Mountains.

Name.	When built.	Dam.				
		Maximum height.	Top width.	Top length.	Outer slope.	Water slope.
		Feet.	*Feet.*	*Feet.*		
Dome Lake [a]	1905-6	29	15	1,080	1 on 1½	1 on 3
Colorado (7)	.....	10	10	100-1,100	1 on 1½	1 on 1½
Consolidated	1899	18	9	200	1 on 1½	1 on 2
Last Chance	1899	12	5	228	1 on 2	1 on 3
Clouds Peak [b]	1906	20	10	450	1 on 2	1 on ½
Kearney Lake	1904	45	10	700	1 on 1½	1 on 1½

Name.	Outlet.		Wasteway.		Capacity.	Area.	Average depth.
	Kind.	Size.	Depth.	Width.			
			Feet.	*Feet.*	*Acre-feet.*	*Acres.*	*Feet.*
Dome Lake [a]	Concrete	3 by 4 feet	Natural.	.....	1,300	92	14.0
Colorado (7)	Pipe	.....	2	8	500	75	6.6
Consolidated	Wooden box	12 by 12 inches	2	10	200	25	20.0
Last Chance	Lap-welded pipe.	12-inch	2	30	125	24	8.3
Clouds Peak [b]	Concrete	3 by 5 feet	.....	.....	3,000	170	17.7
Kearney Lake	Pipe	24-inch	.....	.....	3,800	150	25.3

[a] Earthen dam, with clay-puddle core. [b] Rock-fill dam, not completed.

RESERVOIRS ON THE PRAIRIES.

The conditions under which the reservoirs on the prairies are constructed and operated are entirely different from those of the reservoirs in the mountains. The precipitation in the mountains is much greater than that on the prairie and is different in character, the former being for the most part snow, while the latter is largely rain. Tributary catchment areas on the plains are covered only with buffalo and kindred grasses, while different climatic conditions cause the snow to lie in the mountains long after it has disappeared on the plains below. Because of these three differences the run-off from the mountains is much larger, less irregular, and less erratic in intensity than that of the plains.

For the reasons set forth, one may travel many miles over the prairie region during the greater part of the year without seeing either spring or running stream, and at such times the parched condition of the ground is beyond conception. Until very recently all of the plains were used to pasture stock and sheep, and enormous ranges, whose limits were defined only by the distance herds of cattle might advantageously travel for water, were controlled by the ownership of a single water hole or spring. Beyond these ranges there remained thousands of square miles of nutritious pasturage which for lack of water were useless for the greater part of the year. In driving cattle and sheep to market, water for drink while en route is very important, and to obtain it in early days, long and circuitous routes between the range and point of shipment were necessary and very often entailed great loss in weight of animals while on the trail. Besides this, through a large section of the country in question the well water is unfit for man or beast. In order to extend the range, therefore, and to provide water for stock as well as domestic purposes, it became essential to conserve in small reservoirs the flood waters, which for short periods at certain times of the year are quite plentiful. By the construction of a few small reservoirs the stockmen increased their range to a considerable extent and pointed the way whereby the great plains could be made available for grazing purposes.

RESERVOIRS OF THE CHICAGO AND NORTHWESTERN RAILWAY.

Following closely in the footsteps of these pioneers, the management of the Chicago and Northwestern Railway, which had pushed the northern and western terminals of its lines to Bellefourche, S. Dak., and Casper, Wyo., respectively, determined to insure the shipment of the cattle to market from these two points by means of small reservoirs spaced at convenient intervals along well-defined routes leading thereto, affording the shipper a well-watered trail between the range and the shipping point. After a careful exploration by the engineers of this company, a large number of reservoirs

were constructed. The success of this plan is shown by the fact that 2,500 cars of cattle are annually shipped to market from Bellefourche, while there are shipped annually from Casper 600 cars of cattle, 1,100 cars of sheep, and 4,500 head of horses. This represents an annual income of $1,500,000 to the shippers at each terminus, as well as a gross annual revenue to the railroad of $300,000.

SITES.

The search by the railroad engineers for reservoir sites was conducted along several routes radiating from both Bellefourche and Casper and extended for a distance of more than 100 miles. While the rolling prairies abound in sites, diligent search was necessary to discover those fulfilling the required conditions, the principal ones of which are as follows:

The reservoirs must be located in certain general directions at intervals of about 12 miles, which distance permits moving the herd from one reservoir to the next between late in the afternoon of one day and early the following morning, the herd moving very slowly and grazing on the way. By so doing the cattle and sheep are near water during the heat of the day and traveling while it is cool.

For stock purposes a reservoir should also have gently sloping shores, since young animals are likely to drown where there are steep banks. It is necessary also that the floor of the reservoirs be hard and of a material which after being thoroughly wet will afford safe footing for animals and not permit them to mire.

Because of the function of these reservoirs, as well as their scattered positions, they can not with economy receive constant care. In fact, as a rule they are inspected but once a year by an engineer and a repair crew, when all necessary repair work is done. Hence reservoirs must be located in the drainage channels which are to supply them, as the use of feed canals, although affording greater safety, calls for constant attendance. For this reason it is not advisable to locate a reservoir of this character on a stream which at times of heavy downpour will deliver volumes of water far beyond the storage capacity of the reservoir, for the rupture of one of these dams will throw the reservoir behind it out of service for the entire season, thus rendering the chain of watering places much less efficient; but it is essential that there be sufficient tributary catchment area to completely fill the reservoir at least once yearly.

The character of the surface of the tributary catchment area is also of great importance. It should be such as will resist the erosive action of water, for erosion will cause a deposit of silt in the reservoir. Silting not only decreases the capacity of the reservoir, but it renders the floor soft, affording very poor footing for stock.

Another very essential condition for a reservoir site is that the configuration of the surrounding land be such that ample wasteway can

be provided to accommodate the surplus run-off, not only of long-continued storms but of the short storms of great intensity which frequently occur during spring and summer. It is also essential that this wasteway, whether natural or artificial, be easily and permanently maintained.

Lastly, the relative position of the dam and the water impounded should be such that the prevailing wind will blow from the dam to the reservoir, preventing the action of the waves on the dam. This condition is put last not because it is of minor importance but because it is of an accidental nature, the general lines of drainage of the country usually determining the relative position of reservoir and dam, so that to make selection in this regard is often out of the question.

COST AND MAINTENANCE.

During the eleven years preceding 1906 the railroad company constructed 31 reservoirs, 18 of which are tributary to the Bellefourche line and 13 to the Casper line, providing easy access to the railroad for a distance of 100 miles in various directions. Data relative to these reservoirs are tabulated below:

Reservoirs constructed by the Chicago and Northwestern Railroad for watering stock.

Name.	When built.	Dam.			Capacity.		Area.	Average depth.	Original cost.		Cost of maintenance.	
		Number.	Maximum height.	Top length.					Total.	Per acre-foot.	Total.	Annual.
			Feet.	*Feet.*	*Gallons.*	*Acre-feet.*	*Acres*	*Ft.*				
West line:												
Casper Creek	1895	25	13.6	689.0	24,533,500	75.3	21.0	3.6	$1,891.00	$25.11	$3,222.52	$358.06
Powder River	1896	4	24.1	200.0	3,770,800	11.5	2.5	4.6	782.00	68.60	6.68	.84
East Woolton	1897	9	16.0	207 0	4,762,500	14.6	3.2	4.6	550.47	37.70	393.21	56.00
Poison Creek	1895	23	15.3	534.5	19,336,000	59.2	13.5	4.3	1,637.80	27.66	444.43	49.00
Forks	1896	8	16.0	218.0	4,500,000	13.8	3.1	4.4	470.25	34.08	206.25	25.00
Tisdale	1897	10	14.0	234.5	4,975,900	15.5			520.50	33.58	336.50	48.00
Cut Bank	1901	12	17.5	375.0	6,098,400	18.7	4.7	3.9	1,081.91	57.85	8.40	2.80
Cloud Creek	1903	11	14.6	259.0	5,880,600	18.0	3.8	4.8	1,231.30	68.41	250.00	250.00
Sage Creek	1896	28	14.0	259.0	32,413,600	99.2	17.8	5.6	2,287.00	23.05		
Lusk	1898	1	9.0	150.0	2,175,000	6.6	2.0	3.3	85.97	13.03		
Duck Creek	1900	6	12.5	200.0	4,000,000	12.3	3.0	4.1	473.86	38.84		
Badwater Creek	1901	17	14.0	270.0	10,414,400	31.9	8.5	3.8	813.00	25.49	11.75	4.00
Soldier Creek	1904	11a	17.0	319.0	5,880,600	18.0	3.8	4.7	1,009.15	56.06		
North line:												
Crow Creek	1895	15	10.0	450.0	8,430,800	25.8	5.8	4.5	474.45	18.46	906.43	101.00
Dry Creek	1898	2	16.0	352.0	2,400,000	7.4	3.8	1.9	371.56	50.21	320.49	53.00
Roundout	1895	21	12.0	588.6	15,307,400	46.9	10.4	4.5	568.21	12.12	1,553.72	172.00
Box Elder	1895	22	12.0	403.0	17,154,900	52.7	11.7	4.5	550.00	10.42	1,848.47	205.00
Flying V	1895	27	12.0	448.0	28,518,200	87.5	19.5	4.5	909.90	10.39	2,263.16	251.00
Cheese Factory	1895	24	18.0	600.0	23,357,000	71.6	15.9	4.5	1,346.62	18.83	2,793.19	310.00
Montgomery [a]	1895	20	12.0	338.0	12,536,300	38.4	8.6		545.26	14.20	776.29	86.00
Short Creek	1895	19	10 0	327.0	11,158,000	34.2	7.6	4.5	393.13	11.53	687.75	76.00
Battle Creek [a]	1895	26	15.0	950.0	27,697,100	85.0	18.9	4.5	712.25	8.40	2,598.71	288.00
East Cottonwood	1896	30	20.0	435.0	61,068,500	187.4	53.6	5	1,438.00	7.68	475.43	59.00
Corral Creek	1896	29	14.8	468.0	60,646,500	186.1	53.2	5	1,266.00	6.82	745.43	93.00
Bull Creek [a]	1897	16	15.5	392.0	8,825,400	27.0	8.0	4	657.75	24.36	1,433.35	204.00
Indian Spring [a]	1895	13	13.2	345.0	6,192,400	19.0			407.68	21.57	187.99	21.00
New Indian Spring	1900	7	15.0	230.0	4,300,000	13.2	2.8	4.7	427.00	32.35	627.87	158.00
North Butte Creek	1895	14			7,800,000	23.9			1,126.75	47.10	1,317.49	146.00
New Battle Creek	1902	18	15.3	670.0	10,708,200	32.8	11.5	2.9	1,614.00	49.21	26.15	13.00
New Bull Creek	1903	5	16.0	400.0	4,000,000	12.2			719.60	58.99	82.99	83.00
Grouse Creek	1903	3	16.8	240.0	3,052,700	9.3	5.5	1.7	673.36	72.40		

[a] Abandoned.

The reservoirs in the table have been numbered according to their capacity. These numbers are used for identification, both in the diagram of cost of reservoirs (fig. 5) and in the map showing general locations (Pl. I).

The reservoirs vary in capacity from 6.6 acre-feet for the Lusk Reservoir to 187.4 acre-feet for the East Cottonwood Reservoir. The average capacity of those on the north line is 50 acre-feet, of those on the west line 30 acre-feet, while the average for both groups is 43 acre-feet. The areas of their water surfaces when full vary from 2 acres for the Lusk Reservoir to 53.6 acres for the East Cottonwood Reservoir. The average depths of the reservoirs vary from 1.7 feet for the Grouse Creek Reservoir to 5.6 feet for the Sage Creek Reservoir, the average being 4.07 feet. In this connection the small variation of the average depth is remarkable. In nearly every case the average depth is approximately four-tenths the maximum height

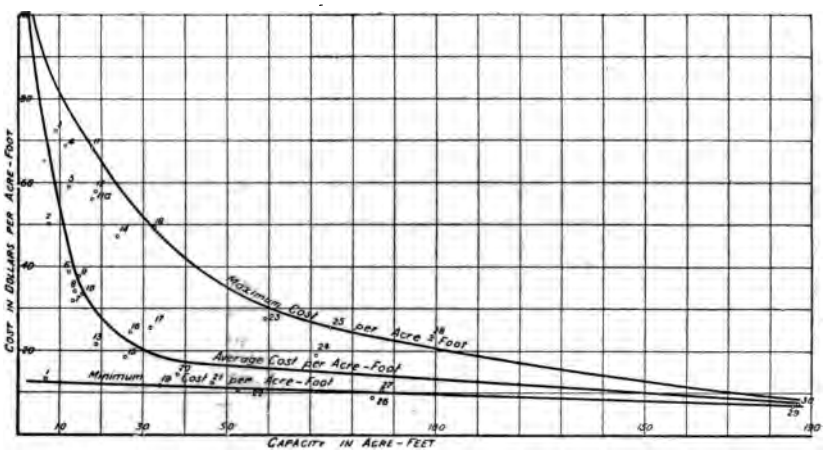


FIG. 5.—Diagram showing cost of reservoirs.

of dam, introducing small error if this portion of the maximum height be used to estimate the storage capacity of the reservoir. The cost of constructing these reservoirs varies from $2,287 for the Sage Creek Reservoir to $86 for the Lusk Reservoir, the cost of construction per acre-foot of capacity varying from $6.82 for the Corral Creek Reservoir to $72.40 for the Grouse Creek Reservoir. From these various items on the cost of construction figure 5 has been prepared. The upper line in the diagram represents the maximum cost per acre-foot that may be expected for reservoir construction under these conditions, the middle line represents the average cost of same, and the lower line represents the minimum. All the reservoirs in question were constructed by contract and are therefore comparable in this respect, and although each reservoir has its own set of local conditions, in general features they are similar. These local conditions

are predominant in very small reservoirs, and large variation in cost per acre-foot is to be expected. As we reach the moderate-sized reservoir, however, there is less variation, and with the larger reservoirs the maximum and minimum cost are nearly identical. The data from which these curves are constructed are probably the best available, though of course where the individual uses his own animals and tools the cost will be materially less.

The cost of maintenance as given is a careful compilation of the railroad records, but in a number of cases the result is misleading, as, in the case of Casper Creek Reservoir, the total for maintenance, given as upward of $3,000, includes a very expensive experiment in wave protection which should be charged to construction. In other cases where the maintenance is very large, such items as the construction of new wave protection or the reconstruction of wave fence partially destroyed by campers, and the reconstruction of wasteways, are included, as well as reconstruction of large portions of the dams damaged by animals. The first item could hardly be classified as maintenance, while the others would probably not be necessary did the reservoirs have constant attention. The cost of maintenance, therefore, does not fairly represent what it would be in case of individual ownership, for in such case repairs would be made as needed, before serious damage was done, instead of only once a year, thus allowing slight injuries to become serious.

The maximum heights of the dams vary from 9 feet in the Lusk Reservoir to 24.1 feet in the Powder River Reservoir, one of the smallest reservoirs having the highest dam. The average maximum height is 14.7 feet. The top lengths of the dams vary from 150 feet for the Lusk Reservoir to 950 feet for the Battle Creek Reservoir, which, however, is not now in operation. The longest dam of those at present in use is the Casper Creek, which has a top length of 689 feet.

The railroad management has abandoned the use of four reservoirs—Montgomery, Battle Creek, Bull Creek, and Indian Spring. This action is quite recent and was made necessary by the deposit of silt in the reservoirs to such extent as to make them absolutely useless; in fact, there only remains in the Bull Creek Reservoir a storage capacity of 1 foot in depth, while in the other three the surface of the silt is coincident with what was originally the high-water level. Bull Creek Reservoir, when built in 1897 had a maximum depth of 9.5 feet of water; when abandoned in 1903 it had a depth of 8.5 feet of silt accumulated in only six years, or at a rate of about 1.4 feet of silt per year. New Bull Creek Reservoir, which is on a fork of Crow Creek, just over the divide from the original Bull Creek Reservoir, was constructed in 1903 to replace the abandoned reservoir. Indian Spring Reservoir, built in 1895, originally stored

water to the depth of 8 feet, but in 1900 it had completely filled with sediment. The silt was deposited in this reservoir also at the rate of 1.6 feet in depth per year. New Indian Spring Reservoir was constructed a short distance from the abandoned reservoir, but within the same general watershed, and is now showing the effect of silt. When visited in 1905, after having been in operation for five years, it contained silt to the depth of 5 feet, leaving an available depth of only 5 feet where there was 10 feet available. It is, therefore, becoming filled with silt at the rate of about 1 foot per year and it is now dangerous for cattle on account of the soft bottom and undoubtedly will soon be abandoned.

Battle Creek Reservoir, constructed in 1895, was abandoned in 1902. Originally storing water to a maximum depth of 10 feet, at the time of its abandonment it was practically full of silt, which had been deposited at the rate of 1.4 feet per year. The New Battle Creek Reservoir, constructed to serve in place of the old one, is located about 2 miles upstream within the same general watershed.

Montgomery Reservoir was abandoned after seven years' use, having in that time filled with silt to a depth of 7 feet, or at the rate of 1 foot per year. No new reservoir has yet been constructed to take its place.

Aside from these reservoirs that have been abandoned, inspection developed the fact that three other reservoirs were becoming silted up and would have to be abandoned in the near future. These are the Cheese Factory, the Roundout, and the North Butte, all of which were constructed in 1895 and have silted up to a depth of from 2 to 3 feet during their ten years of use, or at a rate of 0.2 foot per year. It is not so much because of the decreased storage capacity as because of the miry condition created by the silt that these reservoirs must be abandoned, for bars and shoals are formed, and therein lies the danger to stock. With seven of the thirty-one reservoirs out of service, it is seen that the loss through silt alone during the last ten years has been more than 20 per cent, or about 2 per cent per year.

Although the silt problem was not fully appreciated at the outset, it is now being given very careful study by the railroad engineers. The reservoirs wherein the silt problem has become prominent are, without exception, located along the north line, those along the west line having shown no signs as yet of the accumulation of much silt. Invariably those affected by silt have tributary catchment areas of either "bad land," gumbo, or shale, all of which wash very badly, charging their run-off with a high percentage of silt, to be deposited whenever the water becomes stationary, which is of course when it enters the reservoir.

The dams constructed by the railroad company are of earth, their present standard cross section being the result of ten years of experience in construction and maintenance. Earth was used because it

was the only material available, there being in most cases not a stick or stone for many miles. In constructing the first of these reservoirs no special effort was made to secure a bond between the dam and its foundation, and the sides were given the steepest slope at which the material being used would stand. It was soon demonstrated, however, that a perfect bond between dam and foundation was imperative, and that a much flatter slope on the water side of the dam was necessary to withstand the action of the water. The standard cross section at present has a top width of 10 feet, a water slope of 1 on 3, and an outer slope of 1 on 1½. To insure water-tightness along the joint between the dam and its foundation, the sod is scraped off the foundation for a depth of 6 inches and an intercepting trench dug parallel to the axis of the dam. This trench has been placed in various positions between the toe of the inside slope and the crest of the dam. At present, however, its position is just inside the inner edge of the crest of the dam, as shown in figure 6.

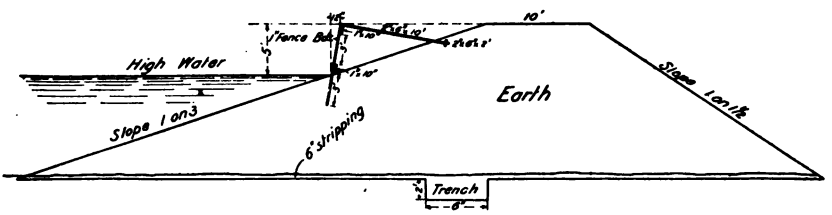


FIG. 6.—Standard cross section of earth dams of Chicago and Northwestern Railway, showing position of intersecting trench.

WAVE PROTECTION.

In the open prairie where the wind has full sweep against the dam, some provision is necessary to protect the slope from wave action, as, with the very frequent high winds, waves having a height of as much as 3 feet are created when the reach is only one-fourth or one-half mile. Four distinct types of wave protection have been used: First, the ordinary rock pitching of the water slope; second, the use of rock pitching laid on a mat of sagebrush; third, live willow trees planted on the water slope, and, fourth, the wave fence.

Rock pitching with or without an underlying mat is very expensive for reservoirs in the prairies, as the rocks nearly always must be hauled a long distance and when obtained are not the kind desired for this class of work, in either character or shape. Usually they are a kind of lime sandstone, easily disintegrated by the action of water, and are of the laminated type in use for flagstones, lacking, therefore, in stability to resist wave action. The rock pitching of the dam of the Tisdale Reservoir about 30 miles northwest of Casper, which was put on in the ordinary way, has not proved very effective (Pl. IV, fig. 1), though the prevailing winds do not drive the waves directly against the dam. After watching the behavior of this piece of rock pitching,

FIG. 1.—TISDALE RESERVOIR, NORTHWEST OF CASPER, WYO., SHOWING ACTION OF WAVES ON PITCHING.

FIG. 2.—RIPRAP ON DAM OF CASPER CREEK RESERVOIR, 12 MILES WEST OF CASPER, WYO.

it was decided that it was necessary to have a mat underlying the stone pitching, and, as sagebrush is very plentiful throughout the plains, it was decided to try a combination of sagebrush mat and rock pitching. About this time the dam of the Casper Creek Reservoir went out for the second time, the first failure being due to wave action and the second to the underground work of groundhogs. In repairing this dam (Pl. IV, fig. 2) the water slope was covered with stone pitching on a sagebrush mat. The work, which was carefully done a few years ago, at a cost of about one-half the original cost of the entire dam, was satisfactory until the underlying sagebrush began to rot. This allowed some of the stones to settle sufficiently to break the continuity of the surface, leaving a weak spot for the waves to attack. At the time of inspection the stone surface was showing signs of failing, and, as this dam has a maximum exposure to the prevailing wind, repairs will soon be necessary in order to prevent another rupture. It is seen from this that the two trials of rock pitching have been very expensive and not a complete success.

Willow trees were planted on the water slope of the Dry Creek Dam to serve as a wave protection. When planted a wave fence was constructed below them to take up the force of the waves while the trees were young. The entire dam was inclosed by a barbed wire fence to protect the trees from the cattle. Some "prairie pirates," however, stole the wire and used a portion of the wave fence for firewood, so the trees have had a hard struggle for existence, only a few of those planted surviving. If the stock can be kept away from these trees a few years they will undoubtedly grow rank and thick and be a great factor in resisting wave action. There is danger, however, of the roots of the trees penetrating the bank and creating leaks, though as the roots will tend to grow toward the water this danger is very slight.

The wave fence has been used to a large extent on the railroad reservoirs as a substitute for a parapet, the cost of which would be prohibitive. The wave fence is a nearly vertical tight-board fence on the water slope of the dam at the high-water level. The boards are 1 inch by 10 inches by 8 feet, pointed from one side to insure their forming close joints, and are driven in the same manner as sheet piling is driven, for a depth of 3 feet into the dam, leaving 5 feet of fence exposed to the waves. To connect the boards and form a solid structure, they are fastened to two strings of 1-inch by 10-inch boards running lengthwise of the dam—one near the tops of the boards and one just above the surface of the slope of the dam. Behind the fence are braces, fastened at one end to the wave fence and at the other to deadmen buried in the dam. The braces are spaced 8 feet apart and afford the fence rigidity against the hammering of the waves. On the wave fences first constructed these braces were fastened to the top of the fence and given a position nearly horizontal, making the

braces about 10 feet in length. Trial, however, proved this form of brace not altogether satisfactory because of its flexibility, and the much shorter brace used in later structures has given much greater satisfaction. The shorter brace is attached to the fence at about two-thirds of its height, and is given a downward inclination of about 45 degrees, giving its exposed section a length of only about 3 or 4 feet. The two kinds of braces used are shown in Plate V.

The wave fence has proved a very efficient structure, and it is questionable whether, with the conditions under which the railroad reservoirs are managed, a substitute could be found that would give satisfaction. A more permanent structure would be much more expensive, with lumber worth $30 per thousand on the ground and stone practically not available, and a cheaper protection, such as brush, would not do, as dependence can not be placed upon it to serve for twelve months without repair or inspection. One objection to the wave fence is that it affords too good an opportunity for campers so inclined to get firewood without any great effort. Though all the fences had been repaired the year prior to our inspection, many of the reservoirs visited had lost large sections of wave fence from this cause. One place where this was particularly noticeable was at the New Bull Creek Reservoir, where about 100 feet of wave fence had been stolen outright, leaving the dam unprotected for this space, with the result that a large slice was washed away by the waves, necessitating immediate and extensive repairs. The change in cross section due to this vandalism is shown in Plate VI, figure 1. The wave fence, however, is not to be considered a permanent structure, replacement of parts being necessary frequently and the entire structure being completely replaced in seven or eight years.

WASTEWAYS.

Another portion of the work fully as important as the wave protection is the wasteway. Its function is to provide a passage for all surplus water during storms without doing injury to the dam. When the railroad engineers constructed the reservoirs under discussion no time was available for studies of the run-off, and recourse was necessary to signs of erosion, high-water marks, testimony of oldest inhabitants, etc., in order to approximate the size of wasteway required. However, little trouble has resulted from their size. Wherever possible, natural wasteways removed some distance from the dams were utilized, though many of the reservoir sites did not provide natural wasteways and it was necessary to construct artificial ones. Without exception, the natural wasteways have given much less trouble in every way than the artificial ones. The bottom of the wasteways in all the reservoirs was fixed at 5 feet below the tops of the dams, so that in emergencies for short periods water to the depth of 2½ and even 3 feet could pass safely. The widths of the wasteways vary

FIG. 1.—WAVE FENCE WITH LONG BRACES.

FIG. 2.—WAVE FENCE WITH SHORT BRACES.

FIG. 1.—NEW BULL CREEK RESERVOIR, SHOWING EROSION WHERE FENCE HAS BEEN STOLEN BY CAMPERS.

FIG. 2.—EROSION OF WASTEWAY OF CROW RESERVOIR, NORTH OF BELLEFOURCHE, S. DAK.

from 50 to 250 feet, it being oftentimes necessary, in order to secure sufficient width, to provide two wasteways, one around either end of the dam, on account of the topography of the land adjacent to the reservoir.

Although the sizes of the wasteways have always been sufficient, erosion of wasteways has given no end of trouble, and their maintenance against this danger has become a problem nearly, if not quite, as important as the silt problem. The cause of the trouble is that, as a rule, where artificial wasteways are constructed, and sometimes when natural ones are used, there is too much fall between the point where the water leaves the reservoir and the point where it enters some water course. For this reason there is usually formed a fall at the latter point which constantly recedes from the natural water course and approaches nearer and nearer the reservoir. As the fall recedes it increases in height and in power to do harm. Eventually it will reach the reservoir and, of course, ruin its storage

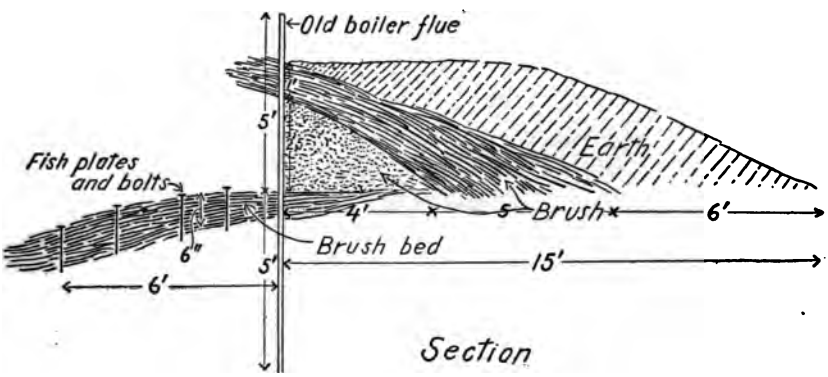


FIG. 7.—Brush drop in wasteway.

capacity. Oftentimes, however, on account of the configuration of the ground it is not possible to provide a new wasteway without enormous expense, and it is necessary either to abandon the reservoir or to repair the wasteway in a manner to insure safety. Plate VI, figure 2, shows erosion in progress in the wasteway of the Crow Creek Reservoir. The banks shown here are about 12 feet high and the channel from 25 to 40 feet wide. An attempt was made to stop the erosion by inserting an ordinary check made of lumber, but this was undermined and demolished the first year it served.

In a number of cases when erosion of the wasteway commenced, brush checks were constructed across the wasteway to prevent further washing. These have been in operation several seasons and have so far proved very efficient, and so long as the brush lasts will probably give satisfaction. However, they are but temporary. All the materials used in their construction are brush, old boiler flues, fish plates, and wire. The arrangement of materials is shown in figure 7. All

brush is made into bundles or fascines securely bound with wire. A bed about 6 inches thick is first made of the bundles by placing them in the bottom of the wasteway, parallel with its direction, the butts being upstream. The bundles are fastened together by wire and fish plates, and through them across the entire channel old boiler tubes 10 feet long are driven at intervals of 4 feet, extending for a depth of 5 feet into the ground. On the upstream side of these boiler tubes more brush is placed for a depth of from 1 to 2 feet and a width of 10 feet, the bundles of brush being placed at right angles to the direction of the channel. Upon the last layer more brush is placed, with the butts downstream and inclined somewhat upward. Lastly, a layer of earth about 12 inches thick is placed over all the brush upstream from the upright boiler tubes. In this manner an artificial fall is created, the falling water dissipating its force on the underlying mattress of brush. Plate VII, figure 1, is a view of a brush check in the wasteway of the Box Elder Reservoir, which was constructed at a cost of several hundred dollars only after one wasteway had been destroyed by erosion and abandoned and a second one threatened with the same end.

Because of the functions of these reservoirs no outlets are necessary, so that one set of problems encountered in the construction of storage reservoirs has not had to be solved by the railroad engineers.

As stated heretofore, the entire work of constructing the railroad reservoirs was done under contract, the average price for moving dirt being in the neighborhood of 15 cents per cubic yard. The specifications under which the work was performed, issued by the chief engineer, are as follows:

First. The surface of the ground under the entire base of dam inside of the slope stakes, as well as borrow pits, must be stripped for a depth of 6 inches at least, and more if circumstances require, so as to get rid of all sod and other light and porous material which would prevent the earth in the dam from settling down in a solid and compact manner, and all of the material so removed by stripping must be taken to points which will be outside the reservoir basin when work is completed and to such a distance from the work as to insure there being no liability of any of such material being scraped back into the dam during construction or washed into the reservoir basin by rains, etc., after the same is built.

Second. After the ground under the base of the proposed dam has been stripped and thoroughly cleaned down to good material and before the grading of the dam is otherwise commenced, a trench of 12 feet in width and not less than 18 inches in depth, or more when the material is such as to require it, shall be dug the entire length of the proposed dam and so that the edge of the trench nearest the proposed reservoir basin shall not be less than 3 or more than 10 feet inside of the slope stakes set for the toe of slope on the side next the reservoir basin. This trench is for the purpose of thoroughly breaking the seam that might otherwise exist between the natural ground and the constructed dam, and for that reason should have its sides cut down as nearly perpendicular as practical; and the material taken from this trench, if of good quality, may be deposited inside the slope stakes in an even and uniform manner along the back side of dam.

FIG. 1.—BRUSH CHECK IN THE WASTEWAY OF BOX ELDER RESERVOIR.

FIG. 2.—BRUSH PROTECTION FROM WAVES ON DAM OF HARRIS RESERVOIR NO. 2, ON TRAIL CREEK, MONTANA.

Third. When stripping has been thoroughly done and trench completed, the whole surface stripped must be refilled and dam built by grading the material up in a good and uniform manner over the whole base of dam in layers of not more than 24 inches in thickness and to the slopes as specified.

Fourth. No borrow pits shall be made across the draw below the dam.

Fifth. Unless otherwise authorized by the chief engineer, the slope next the reservoir basin shall be 3 to 1, while that of the back of the dam to be the ordinary slope for dirt banks of 1½ to 1, and dam shall be 10 feet in width on top. If at any point where a reservoir is to be constructed, the conditions are such as to seem to necessitate proceeding differently with any part of the construction than as set forth above, then the reasons for such deviation shall be stated to the chief engineer and his consent obtained.

Sixth. The dam and wasteway shall be located so that the top of the dam will be 5 feet above the bottom of waste way. Care should be taken to get a location which will, if possible, admit of a natural waste way in direct line with the draw above and so that the dam will be located to one side, so as not to be subjected to the direct force of the stream.

Seventh. Sketch showing cross section of dam and manner of stripping and making trench attached.

Eighth. When the dam is completed, build a wave fence the full length of slope that is reached by the water when reservoir is full, as per plan.

Ninth. Also build a barbed wire fence on iron posts, as per plan furnished, around the outside of toe of slope away from the reservoir, across ends of dam and then parallel with dam, to connect with ends of wave fence.

Tenth. The engineer who stakes out the dam must make an estimate showing cubic yards of material required for dam and waste way. Also the length of wave fence and protection fence around dam, sending same to the chief engineer as soon as possible after the work is staked out, so that order may be made authorizing the work.

The foregoing shows very clearly the method of constructing the dams and wasteways. As the work is performed under the direction and inspection of the railroad engineers, great detail is not necessary. The noticeable features of the specifications are:

First. The provision for stripping the foundation and the introduction of an intercepting trench in order to secure proper bond between structure and foundation and to eliminate sod and other perishable material from the structure. These precautions are to be strongly commended, failure to observe them having caused the rupture of many structures of this sort. It is advisable to supplement stripping by roughing up the stripped surface with some such implement as a cultivator just prior to depositing the first layer of earth, as this will assist greatly in securing a water-tight bond.

Second. The prohibition of a borrow pit in the draw or watercourse below the dam. This is an excellent provision, though seldom followed in reservoir construction, with the result that seepage and storm waters collect in the pit near the foot of outside slope and by capillary attraction saturate the lower face of the dam to a very considerable extent, causing the material to cave and slough off and impair the strength and security of the dam. It is also advisable to

provide that the borrow pit, if made within the reservoir, shall leave a berm of at least 10 feet between the toe of the water slope of the dam and the nearest edge of the borrow pit, to prevent the earth from sliding when the water in the reservoir is drawn down suddenly. The berm will also prevent bodily movement of the pitching if the slope of the dam is pitched, which might occur unless the pitching were carried to the bottom of the pit.

Third. Provision for constructing the dam in layers having a thickness not greater than 24 inches. This means that the contractor will make the layers not less than 24 inches thick, which is much greater than is ordinarily prescribed in earthen dams. However, the height of these dams is not great and all the work is done by horses and scrapers, so that the real danger lies only in the formation of vertical seams where the work from the two ends joins, which will result in serious leaks. If there is any virtue in constructing the dam in layers, it would seem advisable that their thickness be not nearly so great as 2 feet and that provision be made to avoid the formation of vertical joints.

Fourth. No provision as to character of material to be used in constructing dam. This, to be sure, is largely determined by local conditions, it being necessary to utilize the material in the immediate vicinity of the reservoir site because of the great expense of hauling material even from a nearby source. For any locality in the prairies there is not much variation in the character of the soil, most of the reservoirs being in locations where either gumbo, shale, or a mixture of gumbo and sand is the material available. These materials, however, are nearly always impregnated with alkali or other soluble salts to a greater or less degree, permitting of a choice of material with regard to this property, the material having the least quantity of these salts being the most desirable, particularly for the position adjacent to the water slope. Should there be choice in the judgment of the constructor regarding imperviousness, the inner slope of the dam should be formed of the most nearly impervious material, the downstream slope of least impervious, the material between them being graded from front to back according to its imperviousness. The provision against sod in the embankment is a very good feature. All perishable and soluble materials should be avoided because they will produce weak spots either by decomposing or dissolving.

Fifth. No provision for packing the various layers formed during the construction of the dam, either by tamping or the use of water. Under the conditions characterizing the construction of these reservoirs, mechanical tamping is out of the question both because of the size of the job and the difficulty in transporting any such apparatus from one job to the next. Moreover, where horses and scraper used to move the earth the constant tramping of the animals

to pack it to a large extent, particularly if by chance or design the material be damp. Noticeably this is the case where ordinary slip scrapers are used, though the same result may be obtained by the use of large scrapers if care be exercised to distribute each load evenly in a thin layer. The use of water in packing would, if practicable, insure very much better results, but treatment of this character may not be possible because of the absence of water in even very small quantities in the vicinity of a small reservoir site at the time of its construction. In constructing the small reservoirs for the Chicago and Northwestern Railway, dry material was used in every instance, dependence for solidity being placed entirely upon the tramping of the horses. Very rarely, if ever, is water-tightness secured by the use of dry material throughout, the dams of the Chicago and Northwestern Railway being no exception to this general rule. Careful inspection indicated that exceedingly good work had been done on these dams, but despite this fact there is evidence of seepage below nearly all of them. The amount of seepage is often too small for measurement, and is never large, though it indicates that a large portion of the material in the dam is in a more or less saturated condition, which increases the liability to damage.

The soil where these reservoirs are located has always a liberal proportion of gumbo, which with the silt deposited from storm waters prevents leakage to any noticeable extent from the floors and sides of the reservoirs.

It is rather remarkable that through the ten years that the Chicago and Northwestern Railway has been maintaining reservoirs for watering stock, only one failure of a dam (that of the Casper Creek Reservoir, about 10 miles west of Casper) has been due to burrowing or digging of wild animals. No special provision was made to prevent this. The reservoirs are visited only once annually for inspection and repair, and are all located away from the influence of human activity, where the wild animals may work unmolested for months. The country is infested with prairie dogs, squirrels, badgers, coyotes, and other burrowing animals, and more damage from this source would naturally be expected.

PRIVATE RESERVOIRS.

Along with the inspection of the railroad reservoirs, careful inquiry was made regarding reservoirs constructed by private individuals. In most instances the reservoirs were constructed for the purpose of reclaiming land through the desert-land act, under which 320 acres may be secured by the payment of 25 cents per acre at time of filing application; the performance of work to reclaim the land, the value of which shall be not less than $1 per acre annually for three years; the s ission of proof that the entire tract has been brought under

irrigation; the securing of a permanent water right, and the payment of $1 per acre. It is necessary, therefore, that the settler expend in work and money the equivalent of $4.25 per acre to secure title to his claim.

Because the well water for the most part within the zone of investigation is not fit for human consumption and is very often refused by cattle and sheep, it is essential that the incoming settler provide a domestic water supply by storing the storm water in a small reservoir. To be sure the reservoir is often very small and the water after several months' storage deteriorates a great deal in quality, though it is at all times to be preferred to water from wells in gumbo or strongly alkaline soils.

OLIVER RESERVOIR.

This reservoir, constructed within the last few years by Mr. C. Oliver, is located about 7 miles northwest of Bellefourche and about 1 mile from the Crow Creek Reservoir of the Chicago and Northwestern Railway. It is not in the main stream of Crow Creek, but a short distance from it on a small tributary from the east, which furnishes ample flood water to fill the reservoir at least twice during a season. The reservoir has a water surface of about 4 acres, a maximum depth of 5 feet, and a storage capacity of about 10 acre-feet. The cost of its construction was about $200. The site for the reservoir is not a particularly good one, being a fairly wide and flat place in a draw, such as may be found at innumerable places in the rolling prairies. The dam across the draw is 200 feet long and has a top width of 4 feet, both slopes being that of the angle of repose for the material constituting the dam, about 1 on 1½. The maximum height is 8 feet, which exists for a rather large portion of the dam.

The material in the dam is gumbo with a small portion of gritty substance. It was not possible to ascertain what method of construction was pursued, though indications are that the ordinary slip scrapers were used. A large portion of the material was taken from a borrow pit just below the outer toe of the dam, the pit being 2 feet deep with a berm of only 2 feet between it and the dam. From the appearance of the finished work little if any effort was made to secure proper bond between the dam and its foundation, it appearing doubtful whether the sod was disturbed at all before the earth was deposited. The borrow pit, even when the reservoir is dry, contains storm water and seepage, and leakage must be considerable with the reservoir full. Water from the borrow pit has crept up the outer slope of the dam by capillarity and has saturated it to such an extent that serious caving has already begun, and of course will increase rapidly unless steps are taken to prevent it.

The position of the reservoir relative to the prevailing winds is *such* that the waves do not as a rule dash against the slope of the dam,

but against the ridge forming the southeast side of the reservoir. Little effect from wave action on the slope of the dam would, therefore, be anticipated, and the inner slope of the dam was left bare and unprotected. Yet the slope has been affected to a considerable degree, becoming flatter near the toe and more abrupt near the top. The dam has a very ragged appearance and looks particularly weak where the lower slope has been sloughing off, as previously described. In fact, at this place the cross section of the dam has been decreased at least 30 per cent, and unless sloughing is checked at an early date it will probably ruin the structure.

The wasteway was excavated through the low ridge forming the northwest side of the reservoir, and empties directly into Crow Creek. This feature of the wasteway is a very good one, as waste water can in no way endanger the dam, a ridge lying between the two. The waste water enters the wasteway 3 feet below the top of the dam. The wasteway as a whole has a very steep gradient, and the waste water when of any considerable volume has a great velocity. The result has been excessive erosion at the lower end, creating a vertical fall of considerable height. This fall is approaching the reservoir continually, and as it approaches increases in height and power of destruction. Barring repairs to stop its progress, only a short time will elapse before it has rendered the reservoir useless.

The outlet is an 8 by 8 inch wooden box piercing the dam low down at its center and connecting with an irrigation ditch which conveys the water to a meadow on Crow Creek about 1 mile below. At its upper end the outlet is fitted with a wooden slide held in place by cleats fastened to the sides to regulate the discharge. A perforated wooden rod fastened to the slide extends vertically upward well above a platform built over the entrance to the outlet, at such height as to be accessible with the reservoir full of water. From this platform the slide is manipulated, the required height being maintained by the use of pins in the perforations of the wooden rod. This is a very simple and cheap arrangement, and if properly made, so that the slide will form a close joint all around its seat and at the same time not bind, does very well. Without being well made such a gate, however, leaks very badly, and when it binds is useless.

No special effort was made to prevent leakage along the outlet, and as the reservoir was empty at the time of inspection the amount of leakage from this source could not be ascertained, though the indications were that some of the water collected in the borrow pit reached there by following the outside surface of the culvert through the dam.

Silt to a depth of several inches has already been deposited in the reservoir and may in the course of a few years become a troublesome problem, though the character of the watershed would indicate that

this reservoir is rather favorably situated with regard to silt. Indications are that the reservoir will be out of use before the silt problem becomes serious unless efforts are directed toward remedying the defects previously discussed. With these defects corrected there is no reason why the reservoir should not be operated successfully for a great many years.

The water is used to irrigate about 10 acres of meadow land, lying about 1 mile below, for raising blue-stem hay. Being located in a hollow the soil is naturally damp, and crops of 1¾ tons per acre can be grown with only one irrigation and very little care. On similar meadows without irrigation crops of 1 ton per acre are considered large. No seeding or preparing land is necessary for this crop, it being customary to run a disk harrow and a pulverizer over the surface every two or three years. The object of using the disk harrow is to prevent bunching of the grass, and the function of the pulverizer is to grind up and spread the manure and detritus over the land. Taking the annual crop at 1¾ tons per acre, valued at $10 per ton, the gross proceeds from these 10 acres is $175, to obtain which $46 is expended, divided as follows: Farming, $18; irrigating, $6; interest on reservoir investment, $12; repair to reservoir, $20, leaving a net annual income of $13 per acre, or more than ten times the value of the land prior to irrigation.

BRANT RESERVOIR.

The Brant Reservoir is situated on Owl Creek, about 10 miles north of Bellefourche. Just above it on the same stream is the Roundout Reservoir of the Chicago and Northwestern Railway, the two reservoirs being not over a mile apart. The reservoir was constructed five years ago by Mr. Brant, who owns a stage station and road ranch on the main road from Bellefourche to Camp Crook; in fact, the road ran for several years along the top of the dam of the Brant Reservoir. The reservoir was built for the twofold purpose of supplying water for irrigation and for watering the stock of passing herdsmen, thereby assuring custom at the road ranch. Because of its location nearer the main line of traffic, it is now being used for watering stock to the exclusion of the Roundout Reservoir of the railway company, the latter being practically abandoned. The reservoir is bifurcated, the two arms extending upstream for distances of about 1,200 and 800 feet, with an average width of 200 feet, the widest portion just above the dam having a width of about 400 feet. Its area, when full, is about 15 acres, and its capacity approximately 60 acre-feet. The site is one of the best located in that portion of South Dakota, and could, with a reasonable amount of work be made an excellent reservoir for irrigation purposes.

The dam is an earthen structure, 350 feet long, with a bow of

about 40 feet from a straight line in its central portion. This peculiar alignment was evidently made to take advantage of some higher land, though it is questionable whether or not the added length did not more than compensate in the amount of material necessary for the saving due to less height over a small portion of the length. Originally, the dam was given a top width of 8 feet, a water slope of 1 on 2, an outer slope of 1 on 1, and a maximum height of 8 feet. The material used was mostly gumbo. Slip scrapers and horses were used to put the material in place, the dam being carried up as teams and men were available, considerable time elapsing between commencement of work and completion. The material was borrowed from both sides and ends of the dam, the effort being to move the necessary earth with as little work as possible. No particular effort was made to compact the material, though this was very well accomplished by using the top of the dam for a stage road. In spite of this, however, there is evidence of considerable seepage through and below the dam at the place of its maximum height, though not to an alarming extent. The owners were not certain whether the sod had been removed, and an intercepting trench con-

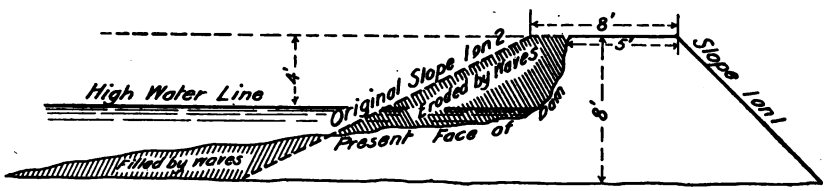


FIG. 8.—Section of dam of Brant Reservoir, showing effect of wave action.

structed in preparing the foundation, but their opinion was that the sod had simply been plowed at the commencement of the work. It is probable, therefore, that much the larger portion of the leakage is along the joint between the dam and its foundation. Although the prevailing wind drives the waves directly against the water slope of the dam, no provision was made to resist their action, and the cross section has been very seriously affected, as shown in figure 8; in fact, on account of the change the use of the top of the dam as a stage road was abandoned. The seriousness of its condition does not seem to worry the owners, though they talk of putting up a wave fence or other protection at some future date. Because of the manner in which construction was prosecuted, anything like accurate data relative to the cost of the dam are not available, though it is probable that it was not in excess of $200.

Around the northerly end of the dam a small wasteway has been excavated with its bottom 4 feet below the top of the dam. This, however, would be inadequate to pass the storm waters of the tributary catchment area of about 4 square miles, were it not that a large

portion of these waters is stored in the Roundout Reservoir before they can reach the Brant Reservoir, thereby retarding and lengthening out the flood wave very materially. As a further safety factor the slope of the ground beyond the wasteway is very gentle, so the waste water may spread out for a considerable distance to the north to an extreme depth of about 12 inches, seeking its way around the north end of the dam into the stream channel below without overtopping it. When the Roundout Reservoir shall have been completely abandoned and out of repair, much improvement in the wasteway will be necessary if the dam is to be kept intact. Aside from checking the rush of flood waters, the Roundout Reservoir has been the means of preventing the accumulation of silt in the Brant Reservoir to a very marked degree, acting the part of a settling basin. In consequence thereof, while there is little sign of silt in the latter, great bars have formed in the former, making the watering of stock a dangerous matter. This is all the more noticeable as the tributary catchment area is comprised of those worthless hills commonly designated as "Bad Lands," which erode to an astonishing degree, loading up the storm waters with thousands of tons of sediment to be deposited as soon as the velocity of the run-off water is checked.

The outlet is a wooden box with the ordinary sliding wooden gate, piercing the bottom of the dam in its highest part and delivering the water into a small ditch leading to the lands to be irrigated. These lands are flat and lie very advantageously for irrigation. So far irrigation is used for watering some trees and grass around the ranch house, one-half acre of vegetables, a small alfalfa patch, and 50 acres of native hay lands.

Most of the land is devoted to native hay because of a prejudice against alfalfa hay. All the products of the vegetable garden are consumed by customers of the road ranch, the revenue from the vegetables being estimated at $150 annually.

It is proposed that the Chicago and Northwestern Railway add to and repair the Brant Reservoir, providing ample storage for both irrigation and stock purposes, for the Roundout Reservoir must be abandoned for stock purposes soon and a new watering place secured to insure a complete chain along this route. It is pointed out that if the Brant Reservoir is enlarged and repaired, as suggested, the expense of maintenance and repair would be less to either party, and that the reservoir would be inspected and repaired more frequently than are the other railroad reservoirs, resulting in a reduction of the cost of maintenance. It would, therefore, at first sight appear to be advantageous to both parties to join in enlarging and maintaining the Brant Reservoir. In order to accomplish the ends sought, however, and insure an equitable distribution, on

water would have to be stored in an upper layer of the reservoir, being drawn off at the upper level of the stock water. As a rule, the irrigation water will have been used before there is great demand for water for stock so that, when most of the cattle are watering, the water will have been drawn down to the bottom of the irrigation outlet, leaving a margin of mud for cattle to mire down in. This would probably prevail against the union suggested. Another objection is the difficulty of dividing the water, which is liable to result in friction and dissatisfaction on the part of both owners. Should this union be effected, however, it would be advisable to keep up the Roundout Reservoir to act as a settling basin to gather silt and a regulator of storm waters. Should this plan be adopted, it is essential that the Roundout Reservoir be carefully watched and provision made against its failure, for a failure of this sort occurring at the time of flood would probably break the lower dam.

HARRIS RESERVOIRS.

The Harris reservoirs are three in number, two of which were constructed at the time of inspection and the third in process of construction. They are all located within 2 or 3 miles of each other in the northwest corner of township 6 south, range 28 east, in the southeastern corner of Montana and about 75 miles northwest from Bellefourche. They are all on forks of Trail Creek, a tributary of Box Elder Creek, which in this portion carries nearly as much water as the Little Missouri River, though the reservoirs are about 6 miles upstream from the junction of Trail Creek with Box Elder.

The first reservoir that Mr. Harris built is the smallest of the three and was built primarily to furnish a domestic water supply, as the underground water in this district is unfit for consumption. This was in 1900, and the idea of irrigating from small reservoirs in that territory had not yet developed. Advantage was taken of an enlarged portion of the bed of the stream which narrowed comparatively at its lower end, at which place an earthern dam was thrown across. The area of the reservoir when full is about 3 acres, its width varying from 400 feet to nothing, and its length being about 600 feet. When filled to the floor of the wasteway it has a capacity of about 10 acre-feet. The dam has a length of 175 feet, a top width of 6 feet, and slopes on both inner and outer sides of 1 on $1\frac{1}{2}$, practically the angle of repose for the material used. Its maximum height is 12 feet. The material used was almost pure gumbo, borrowed from within the reservoir and at a point outside the reservoir some distance apart from the structure, the necessity for this being recognized even in this small affair. Being built in the spring, advantage was taken of rains to secure damp material. A common slip scraper and one team were used in construction, the horses tramping the damp gumbo

sufficiently to secure a dam through which there is apparently very little leakage. Three weeks with one man and team were consumed in construction, which, at $4 per day for man and team, would be in the neighborhood of $80 or about $8 per acre-foot of storage capacity.

Soon after the reservoir was completed it was filled with flood waters, and considerable trouble was encountered in maintaining the inner slope of the dam against the action of water and waves, though the direction of the prevailing winds is from the dam. The steep slope of 1 on 1½, however, was quite susceptible to the action of waves caused by occasional winds coming from the opposite direction, and of ripples constantly playing against the dam. To prevent damage Mr. Harris devised his brush protection, a very interesting feature of this small dam (Pl. VII, fig. 2).

Because of the scarcity of large brush, buck brush and rosebushes were used. It was thought that on account of their character and shape the buck brush and rosebushes not only would form a more compact and tougher dressing, but that they would resist disintegration for a longer period than sagebrush. The pieces are all very small, usually mere whips not over 2 feet in length. The brush was cut with a mowing machine, it being necessary to search over many hundreds of acres to get five wagonloads of a wagon fitted with hayrack, enough to cover the 2,000 square feet on the inner slope of the Harris dam. The brush was spread on the dam in a layer 3 feet thick, care being taken to lay it lengthwise in the direction of the slope. As the brush was spread, such logs as were available were laid on top of it, parallel with the axis of the dam, in order to prevent the wind from disturbing the brush, and, after the entire length of the slope was covered with a mattress of this sort, posts 7 or 8 feet long were driven about 5 feet into the dam and the logs fastened to these with wire. The intervals between these posts depended upon the length of the logs. The strings of logs were placed about 6 feet apart. Because of the shortness of the brush it would seem that these should be closer together, but Mr. Harris has found that this distance serves admirably. The brush settled after being put in place, the mattress 3 feet thick finally settling to a thickness of about 12 inches. According to Mr. Harris, enough brush to cover 1,000 square feet in this manner can be cut with one mowing machine in one-half day, and it can be spread and fastened in another one-half day, the cost being, therefore, not to exceed $4, or less than 0.5 cent per square foot. As seen in Plate VII, figure 2, the brush covering has not been carried down the slope as far as it should be, it being at first thought that protection was needed for only that portion of the slope subject to the action of waves with reservoir full or nearly so. As a result, the waves and water at lower stages have formed an abrupt drop near its foot. Mr. Harris stated that he intends to correct this at the first opportunity.

The brush protection has certainly proved very efficient and inexpensive in this case. Where a reservoir receives constant watching and attention, it would appear that this character of wave protection would serve very well, though it is not permanent and the repairs will amount to replacing the brush entirely every few years. This one has been in service for two years with very little repair, but it has not been buffeted constantly by waves, caused by prevailing winds, but only those caused by occasional winds. Notwithstanding the repairs, the brush protection, though it should be thicker and stronger, is a very cheap and efficient one. Such protection, however, would probably not be successful on dams inspected not oftener than once a year, such as those of the Chicago and Northwestern Railway.

The wasteway of this Harris Reservoir is a natural one, covered with the native sod. It is formed by a sweeping bend in the creek, and extends for 250 feet to the west of the westerly end of the dam, its bottom being 2½ feet below the top of the dam. During a flood, when the waste water amounted to approximately 500 cubic feet per second, it carried water to a depth of 1 foot, bringing the top of the water only 18 inches below the top of the dam. Fortunately, in this particular instance, there were no waves of consequence beating upon the dam, so that it remained intact. Because of that flood Mr. Harris intends to add 2 feet to the height of this dam, which will undoubtedly form a wasteway amply large for extreme emergency. Beneath the wasteway some porous stratum causes a very considerable loss to the reservoir through seepage, the water, which is palatable as it leaves the reservoir, being hard and strongly mineralized as it emerges below the wasteway. The loss from this source is continually increasing, because the water is enlarging its subterranean channel by carrying away a large amount of soluble salts. As the water is never discolored when it reappears it is reasonable to suppose that no erosion is taking place, and in consequence no alarm has been felt save for the loss of stored water. Some exploring has been done to determine where the trouble lies, but as yet no remedy has been tried. It is probable that filling in good earth just above the wasteway and packing it well with sheep or hogs as it is deposited will tend to prevent further leaking if carried to sufficient height to cut off the porous stratum.

The catchment area of this reservoir is some 5 square miles in extent, and being well covered with native sod it has given little or no trouble with silt, and little trouble need be apprehended. The fact that approximately 500 cubic feet per second has passed through the wasteway would indicate that the area of the catchment basin is too large for the capacity of the reservoir.

The stored water is used for domestic purposes, to furnish ice for the summer, and to irrigate a vegetable garden of 1⅓ acres, being

assisted in the latter service by the liquid manure from the sheep shed during the feeding season, which, with a flock of 8,000 sheep, is in itself quite an amount. The value of a supply of ice and vegetables can not be gauged by the market value of the products, for by having ice through the summer, fresh meats, milk, butter, etc., may be kept, and with a garden fresh vegetables may replace the monotonous diet of canned goods, making the place a pleasant home and the keeping of hired men easy, which, under ordinary conditions, it certainly is not. One acre of this vegetable garden last year produced 2 tons of potatoes, while the remainder produced an ample supply of tomatoes, beans, peas, lettuce, beets, celery, radishes, etc. It is estimated that this garden saves $100 to $200 per year, and adds infinitely to the comfort of those using it, while the cost to maintain it is not greater than $30 per year. From this it will be seen that the reservoir has more than paid for itself from this source alone, saying nothing of its value for ice and for domestic supply.

From the benefits derived from this reservoir and from the fact that he believes it a sound business venture to winter feed his sheep, Mr. Harris conceived the idea of raising alfalfa on lands irrigated from small reservoirs. After considerable exploring, two reservoir sites were located about 2 miles above the small reservoir just discussed. With these two reservoirs, it is the intention to reclaim lands under the desert-land act. At the time of inspection one had just been completed and the other was under way, the contract price in each case being 12 cents per cubic yard of earth measured in the embankment. The contractor is one of Mr. Harris's nearest neighbors, being located about 25 miles away, who wishes to get revenue from his teams when not needed for his own work, which probably accounts for the comparatively low price. The water surface of the reservoir already completed will, when full, be about 20 acres, with a storage capacity of about 85 acre-feet. The reservoir is upward of 1,500 feet long, with widths varying from 800 feet to nothing. The site is a fairly good one, though not particularly advantageous. The dam has a length of 500 feet, a top width of 6 feet, with water slope and outer slope of 1 on 3 and 1 on 1½, respectively, Mr. Harris profiting by the lesson learned in using steep slopes in his first reservoir. The material in the dam is gumbo for the most part, there being very little sand or other gritty substance mixed with it. Because the dam was built during the spring and summer, the material placed in the embankment was somewhat damp. Slip scrapers and plows were the only implements used to move the earth, which was fairly well packed by the tramp of the horses. The layers were not thick and the danger of vertical cracks was avoided.

Material was borrowed from both above and below the dam, leaving a substantial berm between the lower borrow pits and the

FIG. 1.—OUTLET OF HARRIS RESERVOIR NO. 1.

FIG. 2.—GRIFFIN RESERVOIR, 6 MILES WEST OF CHEYENNE, WYO., SHOWING REVETMENT.

toes of the slopes. Still, the structure would be less liable to damage if the lower borrow pit were omitted, but this would have increased the cost of the work. When visited no provision had yet been made to guard against wave action on the dam, though, in spite of the fact that the prevailing winds will drive the waves away from the dam, Mr. Harris will protect the water slope with a mattress of brush similar to that on his first dam. It is his intention, however, to substitute stout wire for the logs, placing the wires much closer together than the logs, and using posts much shorter than in his other reservoir. This should improve the protection, for when the water is high in the reservoir the logs exert quite an appreciable pull on the posts and are likely to be wrenched loose by the waves, whereas the wire will always exert a contrary influence. The use of sagebrush in place of buck brush and rosebushes is also being considered, as gathering a supply of the latter to protect three dams is not a small undertaking and sagebrush is plentiful.

It was the intention to utilize a sod-covered slope around the easterly end of the dam for a wasteway, the slope being away from the dam. Through a misunderstanding, however, the contractor cut a wasteway in the top of this slope, very materially reducing its efficiency. The sod would probably have prevented erosion, while, with the sod removed, erosion will surely begin as soon as the water runs through it, and, unless provided against by a check or drop of some sort, will cause much damage during the first season. It is possible that the wasteway may be filled in, the dam slightly raised, and the surplus water wasted over the sod-covered slope at the other end of the dam, which, however, is not nearly so good a wasteway as the original one.

The catchment area is about 3 or 4 square miles in extent, well sodded, so that the deposit of little silt is anticipated. From experience with the smaller reservoir it is thought that this reservoir will probably fill twice each year.

A wooden box outlet pierces the bottom of the dam where its height is greatest. The box is made of 2 by 12 inch and 2 by 8 inch planks, spiked together to form a clear rectangular opening 6 by 12 inches, the longest dimensions being vertical. The end where the water enters is beveled at an angle of about 45 degrees. The upper one-third of the beveled opening is covered by a lid hinged at its upper end and fitted with a rubber seat. To this lid is fastened a vertical pole extending upward above a platform above high water. The upper end of the vertical rod is connected with a horizontal lever by which the lid at the entrance of the outlet is operated. The end of the horizontal lever travels between two perforated upright guides, a pin passed through the perforations holding it in any desired position. Plate VIII, figure 1, shows this, as well as the

entire platform structure, giving a very good idea of the character of timber available in this portion of the country, and this in very meager quantities. In placing the outlet through the dam, no special effort was made to interrupt seepage along its surface, and nothing could be learned which would throw any light as to whether leakage was to be expected. The cost of this dam without wave protection was in the neighborhood of $500, or slightly in excess of $6 per acre-foot of capacity.

The third reservoir to be constructed by Mr. Harris was just fairly begun at the time of inspection, and little could be learned regarding it. When completed it will be the largest of the three reservoirs, having a water surface of about 25 acres and a storage capacity of over 100 acre-feet. The dam will be slightly higher than the dam just completed, though the same shape of cross section will be used in it. The work was of the same general type as that just described, except, being later in the season, the rainfall made it possible to secure damp earth. Work was being carried on more rapidly than on the other dam, from which much greater settlement and seepage may be anticipated. Borrow pits are being made both above and below the dam, leaving a substantial berm between dam and borrow pit. The outlet is to be ironstone sewer pipe for the culvert, with a cone moving in and out at its upper end to regulate the amount of water admitted into the pipe. Mr. Harris has not worked out completely the details of this regulator, but doubtless will succeed. The cone has a great advantage in making a closer joint than can be made by a flat lid or sliding gate. It is estimated that this reservoir will cost about $750.

The water stored in these two reservoirs is to be used to irrigate some 150 acres of alfalfa, to reach which it will be necessary to construct a ditch 1¾ miles long from one reservoir, and another 3 miles long from the other. These ditches will follow down either side of Trail Creek, the land to be irrigated lying between them. The ditches will cost between $1,600 and $2,000, which, with the cost of the reservoirs, will mean a total expenditure of probably $3,000 for a desert-land claim of 320 acres. Including the purchase price of the land, more than $10 per acre will have been expended, instead of the $4.25 required by the Government. On these 150 acres Mr. Harris intends to raise alfalfa for feeding sheep during the severe portion of the winter. With good treatment this land should produce at least 3 tons of alfalfa hay per acre annually. At the market price of $5 per ton, which is very reasonable for this locality, the annual gross receipts would be $15 per acre. Expenditures on this land for preparing, seeding, etc., would not be greater than $6 per acre and for interest on investment $1.20 per acre, leaving a net annual return of $7.80 per acre, or a total of over $1,200 per year for the 150 acres. At

this rate, neglecting the cost of maintenance, which should be small, the reservoirs will have paid for themselves within three years after their construction. But Mr. Harris is a sheep man, having at the time of the visit a flock of about 8,000 sheep, and it is his intention to use the alfalfa hay with native blue-stem hay for feeding his sheep 90 to 100 days during the winter, increasing both the size of the animals and the amount of wool produced. Assuming that it takes 4 pounds of hay per head of sheep per day, one head would consume 360 pounds during a 90-day winter-feeding period, and a crop of 3 tons per acre on the 150 acres of alfalfa would feed 2,500 sheep. Mr. Harris estimates that by winter feeding he will increase the wool clip per head by 1½ pounds per year, and that the increase in size and weight of the sheep will be at least 20 pounds per head. But it will be assumed, for safety, that the wool clip will be increased but 1 pound per head and the weight but 10 pounds per head. Aside from this gain, the loss of sheep winter fed is practically nothing, while reliable flock masters assert that the loss through winter ranging is at least 10 per cent per year. Summing these facts up for 2,500 sheep and using the market price gives the following result of winter feeding:

Profits due to winter feeding of sheep.

Gain in wool, 2,500 pounds wool, at 20 cents	$500	
Gain in mutton, 25,000 pounds meat, at 5 cents	1,250	
Gain by avoiding range loss, 250 head, at $4	1,000	
Gross gain		$2,750
From which we must deduct—		
Cost of farming 150 acres at $6	900	
Interest on $3,000 investment	180	
		1,080
Net gain		1,670

From this it appears that with good management the reservoirs in this case will pay for themselves in two years, and that by feeding sheep Mr. Harris will gain over one-third more than by selling his products at market prices.

GRAY RESERVOIRS.

The Gray reservoirs are five in number, located in the channel of Black Trail Creek, a tributary of the Little Missouri River, having its head in the Finger Buttes, a very rough and prominent range of mountains. Mr. Al F. Gray is constructing these reservoirs to reclaim 320 acres under the desert-land act, which a few years ago were within the range of the famous Hash Knife Horse Ranch, which has been abandoned and the stock disposed of. Mr. Gray was connected with the Hash Knife Ranch, and upon its abandonment perceived that

in order to succeed in stock raising under the changed conditions, a certain amount of farming was essential. To farm successfully meant to irrigate. The Little Missouri River has cut a deep channel, necessitating long and expensive ditches to get water upon the land by gravity, and, because of its erratic character and the present low value of land, pumping would not be economical. By the construction of an expensive ditch from the Little Missouri, supplemented by considerable storage, a large tract of land could be irrigated, but this is far beyond the financial means of even the most fortunate settlers. Mr. Gray selected Black Trail Creek as fulfilling the conditions under which he could operate. The channel of this creek is rather large, well defined, and has very uniform and nearly vertical banks of considerable height on either side. Judging from the character of the stream bed, it falls very rapidly in its course to join the Little Missouri, and along its length no very favorable sites for reservoirs were observed. The five reservoirs chosen by Mr. Gray are located where the stream widens somewhat, though not to any great extent. The distance between the highest and the lowest of these reservoirs is about 2 miles. The area of their water surfaces will average about 2 acres each, with capacities of between 10 and 15 acre-feet, giving a total storage capacity of 60 acre-feet. The lengths of the dams vary from 100 to 150 feet, and each has a top width of 10 feet, a water slope of 1 on 3, and an outer slope of 1 on 1½. The maximum heights, which in each case extend over a rather large portion of the length of the dam, range from 15 to 20 feet.

Gumbo is the material used, it being put in place by slip scrapers and teams. There was no sod, detritus, or perishable material to be removed, but no provision was made to secure a good bond between the structure and its foundation, to select material, or to have it moist during construction, dependence for solidity and imperviousness being solely upon the tramping of the horses. The material for the dam was borrowed, however, from the ends of the dam and within the reservoir, avoiding a borrow pit below the toe of the outer slope. There is a total of about 9,000 cubic yards of material in all the dams, and Mr. Gray states that construction took the equivalent of one man and team one year. In this way the cash outlay was small, though at the current price of labor the cost was 10 cents per cubic yard of material, the total cost being $900, or $15 per acre-foot of storage capacity. Were the work done by contract the customary profit would have to be added to this amount, making the cost about 13 cents per cubic yard and $20 per acre-foot of storage capacity.

The material was deposited in layers about 12 inches thick, each layer being continuous for the entire length of the dam. The tops of the dams were uniformly 4 feet above the banks of the creek on

either side of the reservoir. These dams are all situated so that the prevailing wind will drive the waves directly against them. The exposed water surface is small but the winds are often severe, yet up to the time of inspection no steps had been taken to provide wave protection. Mr. Gray, however, realized that something of this character was necessary and had in mind using a combination of barb-wire fence and sagebrush. The barb-wire fence will consist of stout posts spaced about 16 feet apart and firmly embedded in the dam, and six strands of barb wire stretched very tightly at equal intervals between the tops of the posts and the surface of the dam, the foot of the fence being just below the high-water mark. The triangular space just above the fence will be completely filled with sagebrush tramped into place and covered with a layer of earth to prevent it from being disturbed by the wind. As the sagebrush settles, more will be added, and by this method it is hoped to maintain a mattress of brush which will effectively protect the dam. This method of wave protection forms something in the nature of a parapet. This parapet, however, protects only a narrow strip of the dam slope, and in order to completely protect it at all stages of the water, it is necessary to construct a series of these structures, the top of each being nearly level with the foot of the one next above. By this treatment the upper faces of the dams would become a series of steps or terraces. No estimate had been made regarding the cost of this wave protection.

In none of the reservoirs is there a natural wasteway, but Mr. Gray's intention is to force the surplus water to spill over each bank of the creek, flow around the ends of the dams on the sod-covered lands, and find its way back into the stream before reaching the next lower reservoir. The ends of the dams have been strengthened by wing levees to prevent the surplus water from doing it damage. It is doubtful if this will prove satisfactory, though it is desirable to have the waste water run over sod-covered land. Should a wasteway be cut into the land, very expensive structures would be required to prevent erosion, and, as it is, great masses of material will certainly be washed out where the waste water falls over the steep banks to reenter the stream.

A wooden box outlet pierces each dam at its lowest place. The culverts are practically on the surface of the original soil, as it was not considered necessary to excavate trenches for them. The character of the gates to be used had not been determined upon. No provision was made to prevent leakage along the length of the culvert, other than carefully packing the material deposited around it. A layer of riprap composed of rather small rocks was placed on the lower slope of the dam for a few feet around the lower end of the culvert to prevent outflowing water from doing it damage.

The accumulation of silt promises to be serious in these reservoirs. The Finger Buttes at the headwaters of Black Trail Creek are hills possibly 1,000 feet high, eroded into numerous fantastic shapes, and it appears that erosion is still in progress. Black Trail Creek will carry a large share of this eroded material and, having a rapid fall, will not deposit it until checked in its course by the upper of Mr. Gray's dams. To this will also be added the erosion from the lower-lying lands composed chiefly of gumbo. Upon drying after a heavy rainfall, the surface of this gumbo is checked and divided by small cracks into small cubes, presenting a surface not unlike that of air-slaked lime. This surface is very susceptible to the action of water, and with each storm great quantities of material are washed into the streams and eventually are deposited at some lower point. With a series of reservoirs in the same stream bed, practically all the silt for the first few years will be deposited in the upper reservoir, which will serve as a settling basin. Because of the great quantity of water, however, which must pass this reservoir to supply those below, the proportion of silt deposited in the upper reservoir to its storage capacity will be abnormally large. It is probable that under these conditions the rate of accumulation of silt will be much greater than was indicated in the extreme case of the reservoir constructed by the Chicago and Northwestern Railway, and it should not be surprising if it exceeds a depth of 2 feet per year. At this rate the upper reservoir will be useless in six or seven years and the efficiency of the system reduced 20 per cent.

The lowest of these reservoirs occupies a position to command the irrigation of the entire tract to be reclaimed, and from this reservoir a supply ditch has been constructed. It has a bottom width of 8 feet, is to carry water to a depth of 1 foot, and has a grade of about 1 foot per 1,000 feet. Its capacity is approximately 18 cubic feet per second, the water having a velocity of 2¼ feet per second. The placing of a number of reservoirs in tandem in this manner is not altogether advantageous, though sometimes made necessary by circumstances. Should the upper reservoir fail in time of flood it will add materially to the size and force of the flood wave, very probably resulting in the destruction of the reservoir next below, which in turn will give greater size and force to the flood wave, and so on down the stream until all the structures have been wiped out. If one reservoir had been constructed away from the stream bed there would have been but one dam to watch and repair. To be sure, a supply ditch must be constructed to carry the water from the stream to the reservoir, but by regulating the flow of this ditch there would be no danger from destructive floods and the danger attending wasteways would be eliminated. The silt problem would also be very much modified, as a very large

per cent of the silt in the storm water would be deposited near the head of the supply ditch, where the velocity of the water would be retarded. This would mean that the supply ditch would require more or less cleaning, though this could be reduced to a minimum by the use of sand boxes.

The land irrigated by this system of reservoirs is to be devoted for the most part to raising native blue-stem hay, though a small portion will be planted to alfalfa, the area of which will be annually increased. It is estimated that with irrigation a crop of 1½ tons of native hay per acre can be grown, while a return of 3 to 4 tons of hay per acre is expected from the alfalfa. This farming will be used to supplement the range, and it is estimated that sufficient winter feed will be harvested from it to comfortably sustain for a ninety-day period a herd that during the summer will require a range pasture of upward of 5,000 acres. By this treatment the size and quality of the stock will be greatly improved. Mr. Gray was not prepared to say what the money value of the result would be, but he did state that, although the cost of his work was greatly in excess of the $4.25 per acre required by the Government on desert-land claims, in his opinion the reservoirs would pay for themselves within a few years.

BARBOUR RESERVOIRS.

Like the Gray reservoirs, the Barbour reservoirs consist of a series of three arranged in tandem in a single stream. They are, however, much closer together. In fact, with the reservoir full the water in one reservoir is backed up to the foot of the dam of the reservoir above.

The construction and operation of these reservoirs is a very good example of what may be accomplished by patience, diligence, and perseverance in conserving flood waters under rather unfavorable conditions. The country in which they are located is rolling and rather steeply inclined, and the stream upon which they are located is too small to afford a name. The site for the reservoirs is a place where erosion excavated basins, flanked with steep banks. The reservoirs serve the twofold purpose of storing water and preventing further erosion.

The reservoirs were built several years ago on a small tributary of the Bellefourche River and about 5 miles northeast of the town of Bellefourche. The three reservoirs do not vary much in size, their aggregate length being about one-fourth mile and the distance between the dam of the lower reservoir and the upper end of the upper one is not more than 1,500 feet. Their average width is approximately 200 feet. The total area of water surface with reservoirs full is approximately 7 acres and their combined capacity 25 acre-feet. The lower reservoir is regular in shape, while the

other two are bifurcated by sharp ridges. Figure 9 is a sketch of these reservoirs showing their relative positions. The catchment area is approximately 1 square mile, which would seem to be insufficient to furnish water enough for the three reservoirs. There is evidence, however, that there is a surplus after filling the three.

The dams are all earthen structures similar in design and construction. Their lengths vary from 100 to 150 feet, and originally they had a top width of 10 feet, a water slope of 1 on 2, and a rear slope of 1 on 1½. The material is a mixture of gumbo and silt, a combination quite easily eroded and dissolved. This, however, is the only material available.

No data could be gathered at first hand regarding the method of construction. From observation, however, it appeared that ordinary slip scrapers and horses were used to move the earth and that material was borrowed indifferently from above and below each dam. The evidences of seepage below each dam, though not alarming, indicate that no particular effort was made to obtain damp

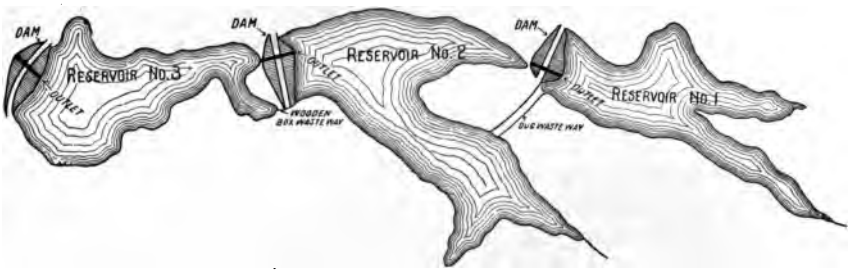


FIG. 9.—Sketch showing position of Barbour reservoirs.

material or to thoroughly compact that obtained or to secure good bond between structure and foundation.

The direction of the prevailing wind is rather quartering to the dams, and the high banks flanking the reservoirs doubtless reduce their force materially. It is probable, therefore, that the waves are not so high nor their force so severe as in some of the cases noted previously. Such waves as there are, however, have given the upper two dams a terraced appearance in place of the regular slope. The top widths have been reduced, notably in one case, where it is now less than 6 feet. Effort has been made to prevent this in one dam by means of a tight board fence, the boards being vertical and driven into the dam at the high-water line. No braces were provided to give the fence rigidity, and at the time of inspection it was in a very dilapidated condition. At the lower dam small cottonwood trees have been planted as a wave protection. These trees at present are very small and rather too widely scattered to be effective, though they are thrifty in appearance and will doubtless be of great use later.

If built by contract, it is estimated that the entire cost of the three reservoirs would amount to about $250, or $10 per acre-foot of storage capacity. It is probable, however, that the work was done by piecemeal, as teams of the owner were available from other ranch work, so that the actual outlay was very much less.

The maintenance of the wasteways of these reservoirs has given more or less trouble. The wasteway from the upper reservoir is dug through the spur that separates it from one arm of the middle reservoir, delivering the surplus water into the lower reservoir. The wasteway is ample, but cutting has begun at its lower end, owing to the rapid fall of the water. This cutting will rapidly travel upstream, and if not stopped by a check or some other protecting structure will soon render the upper reservoir useless. Surplus water is wasted from the middle reservoir into the lower reservoir by means of a wooden box or culvert located at the eastern end of the dam. This water is carried to a small bay in the lower reservoir some distance from the dam. The culvert has a cross-sectional area of not more than 1 square foot and was evidently used to prevent erosion similar to that in the wasteway above. Either the culvert was too small, or seepage along it was not sufficiently guarded against, for at the time of the inspection a large wasteway had been washed around the culvert, leaving it practically useless. Had the culvert been carefully constructed with an apron at its upper end and given sufficient slope, which could have readily been done, the structure would doubtless have proved efficient and would be intact to-day.

The outlets to the reservoirs are all wooden boxes having cross-sectional areas of less than one-half square foot. They are fitted at the upper end with sliding wooden gates, manipulated from footbridges directly above them. Though these outlets are at present working nicely, it will not be long before the wood will decay as do all wooden structures, and replacement by some more permanent material will be very annoying if not difficult.

From the appearance of the stream banks and the character of the soil of the catchment area, it would seem that considerable difficulty would be encountered because of silt depositing in the reservoir, but so far the amount deposited even in the upper reservoir has been very small. This is due, first, to the fact that the surface of the tributary catchment area is well sodded with native grasses, and, second, to the fact that the capacity of the reservoir is comparatively large in proportion to the area of the catchment basin, it being probable that the reservoirs are filled but once a year. The indications are, therefore, that this relation has an important bearing upon the silt problem and that in cases similar to this the silt problem is not so serious.

From the lower reservoir a ditch leads the water to the lands to be irrigated. Because of the rapid slope of the land, the ditch is but a

few hundred feet long. The water is used to irrigate about 20 acres, 10 acres of which were last year planted to corn, and 10 acres to alfalfa. The corn crop seemed to be fair, though the ears were small. The alfalfa field was spotted and in need of water. It is estimated that the alfalfa yielded about 3 tons of hay per acre. The land is fine for alfalfa and with careful work should make a very good field.

This is the last private reservoir visited near Bellefourche, those immediately following being located in the Casper territory.

KIDD RESERVOIRS.

The Kidd reservoirs are two in number, both of which were constructed in 1903 to reclaim land under the desert-land act. The smaller of the two was constructed by Mr. Warner on a fork of Broken Horn Creek, a tributary of Powder River, while the larger was constructed the same year by Mr. David Kidd on the main fork of Broken Horn Creek. Both are located in the westerly portion of township 40 north, range 82 west, about 40 miles northwest of Casper in the rolling foothills lying at the base of the southern end of the Big Horn Mountains. The location is ideal for combining irrigation farming and range feeding for sheep or cattle, as there is throughout the range a liberal sprinkling of meadows both large and small which may be readily irrigated by conserving the storm water and which, when thus treated and properly tilled, will yield abundantly.

Knowing the value of water, and wishing his reservoir to reach a maximum efficiency, Mr. Kidd used all possible precautions to make the larger or Kidd Reservoir a success. It has a water-surface area when full of about 8 acres and maximum storage capacity of 60 acre-feet. The site of the reservoir is simply an enlargement of the channel of Broken Horn Creek, just above a long narrow meadow bordering the creek, and is not one of great natural advantage. Across the lower end of this enlargement an earthen dam with a maximum height of 20 feet was constructed. Its length is about 200 feet, the top width 12 feet, the water slope 1 on 3, and the rear slope 1 on 2. The material used for the dam is excellent, being composed largely of coarse grit with sufficient gumbo to obtain a firm bond between the particles.

Realizing the value of experience in this class of construction, Mr. Kidd employed a contractor who had built a large number of reservoirs for the Chicago and Northwestern Railway. The contract price was $1,400, or about 13 cents per cubic yard. The dam is practically water-tight and the settlement in a maximum height of 20 feet is not noticeable to the eye.

An intercepting trench 3 feet deep and 15 feet wide was excavated along the axis of the dam after the foundation had been stripped of all grass and organic matter and plowed. The excavated material was deposited so as to form the toe of the dam. The bottom of the inter-

cepting trench was then plowed and the trench filled with good material. The work for the entire dam was carried up in layers, endeavor being made to have the thickness of each layer not exceed 12 inches. Scrapers and horses were used to transport the material, four horses being attached to each scraper. The thickness of layers was kept well in hand and the material thoroughly packed by the animals after being deposited. The material for the dam was all borrowed from either the wasteway or within the reservoir. The prevailing winds do not drive the waves against the dam, but strike it on the quarter. Notwithstanding this and the further fact that the entire reservoir is well protected from heavy winds by hills and trees, it was deemed advisable to cover the inner slope with rock pitching. Rock in plenty was available on the hills flanking the reservoir on either side, there being a considerable supply of loose individual rocks weighing from 50 to 100 pounds each. To do this work economically, herders tending sheep or cattle in that immediate neighborhood used their time not needed with the flocks in carrying or placing these stones, skidding them down the hill with a sled. By utilizing the spare time of men in this manner, about four-fifths of the slope was paved at the time of inspection and with very little additional cost. Great care was exercised in placing these rocks so that they would present an even surface and have the joints of minimum size. Mr. Kidd was very sanguine of the ability of this surface to resist wave action. However, the rocks used are not of very good quality, and as they were laid directly upon an earthen surface, it will be interesting to watch their behavior. If the waves were beating directly upon it, the efficiency of the pitching would be very doubtful.

Because the hills rise rather abruptly on either side of the reservoir, no natural wasteway is available. Therefore an artificial wasteway was built around the south end of the dam with a reenforcing levee parallel to the wasteway to protect the end of the dam. The wasteway is 40 feet wide at the bottom, which is 5 feet below the top of the dam. The size of the wasteway was determined by estimating from high-water marks the amount of water passing down Broken Horn Creek in floods, to which a very liberal allowance for possible increase was made. It was well that the allowance was made, for the second year after the reservoir was completed a very heavy storm occurred, the run-off from which was sufficient after filling the reservoir to rise for a depth of 2 feet in the wasteway, the quantity of water escaping being estimated at 250 to 300 cubic feet per second. The wasteway was excavated in sound earth with side slopes of 1 on 2. It returns waste water to Broken Horn Creek about 200 feet below the dam, having a fall of 15 feet in this distance. In reality this fall occurs within 50 feet, and it is remarkable that the wasteway continued to

serve for the two years between construction and the time of our visit. At the time of the storm above noted, however, a weakness due to the burrowing of a badger became manifest just below the wasteway. Here the flood water started erosion, and before the water subsided great rents had been torn below the wasteway, which were rapidly approaching the reservoir, but failed to reach it because of the short duration of the storm. Mr. Kidd appreciated the seriousness of the trouble and expressed the intention of beginning repairs immediately. Below the crest of the wasteway an inclined timber flume will be put in to carry the water nearly down to the level of the stream bed. This will be made of 2-inch planks with correspondingly strong frames and will have plank curtains above and below the structure to prevent water finding its way around it, and at its lower end there will be a short section of horizontal flume to prevent the water leaving it from gouging a large basin and endangering the structure.

The water is drawn off by means of a 7-inch lap-welded pipe which pierces the dam on the northerly side of the stream 4 feet above the lowest point of the reservoir. The outlet lies along the joint between the original ground and the filled-in material. The upper end of the outlet pipe is fitted with an ordinary gate valve, the gate stem being carried upward with the handle on its upper end 2 feet above the top of the dam. A substantial footbridge provides passage to and from this handle. The water is delivered from the outlet into a dividing box, by means of which the flow into the two ditches is regulated. Although care was used to pack the earth securely around the outlet pipe, no special provision was made to prevent seepage along it, but there were no signs of leakage at its lower end.

The surface of the catchment area is well grassed, with a fair sprinkling of trees and rock outcroppings, and the soil beneath the sod will not erode easily; therefore, little apprehension is felt regarding silting. The silt deposited during the two years of the existence of the reservoir is only sufficient to coat its surface with a thin layer as well as to fill the pores in the original floor of the reservoir. This has been no detriment, but has made the surface more nearly impervious to water. It is not probable that silt will ever become a serious matter in this reservoir.

Mr. Kidd placed the cost of the reservoir complete at $2,000, or about $33 per acre-foot of storage capacity.

The smaller or Warner Reservoir was constructed simultaneously with the Kidd Reservoir and in practically the same manner and with the same kind of material, though with a smaller intercepting trench and wasteway. The same form of cross section and the same character of wasteway and outlet were used and the work was carried on in the same careful manner. The site of this reservoir is even more unfavorable than the larger one, being but a narrow gulch with

rather rapid fall. It, however, commands quite a strip of meadow land which, with irrigation, can be made to produce well. The reservoir is about one-fourth the size and capacity of the Kidd Reservoir. Two years after completion the height of the dam was increased 2 feet, and it is the intention of Mr. Kidd to raise it 4 feet higher in the very near future.

Comparatively high hills almost completely hem it in, affording very good protection from wind and waves. It had not, therefore, been provided with wave protection of any sort and after being in use for two years showed no damage from wave action. Nevertheless, as a precautionary measure, it was deemed advisable to place pitching stones on its water slope, and a covering of this sort will probably be put on during the coming year. There is an ample supply of good-sized rocks within easy reach on the surrounding hillsides, which will be hauled down to the dam when there is sufficient snow on the ground to make sledding easy. The rocks will not be placed upon the dam until the ground has thawed and assumed its normal condition.

Although as yet the wasteway has given no trouble, it can not be long before some weakness will develop and repair similar to that in the Kidd Reservoir will be necessary.

The cost of the Warner Reservoir complete was about $400, which, together with that of the Kidd Reservoir, makes an investment of $2,400. At present there are being irrigated about 35 acres of meadow land, and by improvement in methods of irrigation and by increased capacity it is thought that this area will soon be increased to 60 acres. Mr. Kidd is primarily a flock master and uses the produce from the irrigated areas to supplement the range by winter feeding. Of the irrigated area at the time of inspection there were 15 acres of alfalfa, 12 acres of native blue-stem hay, 5 acres of oat hay, and about 2 acres of truck garden and potatoes. The crop harvested from this, together with its market value, is as follows:

30 tons alfalfa hay, at $8	$240	
12 tons native hay, at $10	120	
6 tons oat hay, at $12	72	
3,000 pounds potatoes, at 1 cent	30	
6 bushels corn	5	
110 watermelons, at 20 cents	22	
Other vegetables estimated to save	250	
		$739
Cost of production:		
Farming 35 acres, at $6	210	
Interest on investment, 6 per cent of $2,400	144	
		354
Net gain		385

This gives a profit of $11 per acre per annum. At 10 per cent this represents the interest on land the value of which is $110 per

acre. Without irrigation this land is worth not to exceed $2 per acre for range purposes. The reservoirs have, therefore, enhanced the value of the irrigated land $108 per acre, which, for 35 acres, amounts to an increased valuation of $3,780, about 50 per cent in excess of the actual cost of installing the plant.

However, Mr. Kidd, like Mr. Harris, previously mentioned, does not sell his produce, but maintains that its value is at least doubled by using for feed. He points out that not alone is there an increase in size of animal and the annual wool clip due to winter feeding the flocks for a 90 or 100 day period, but that, by winter feeding, so called "broken down" ewes which would not be able to find subsistence on the range may be kept another winter on feed and an additional crop of lambs obtained. Great stress is laid on this advantage, as ordinarily the range ewes become broken down by losing their front teeth when six years old and must be disposed of at a sacrifice. Also the older the ewes the more likely they are to have twin lambs. It would appear, therefore, that besides an additional wool clip, the prolonging of the service of the ewes one year by winter feeding increases their value slightly over 16 per cent.

In estimating the value of the produce from the truck garden, Mr. Kidd pointed out that with it he furnished vegetables for six sheep camps consisting altogether of nine men. Aside from this he has plenty of vegetables for the ranch house, at which place there are regularly ten men, to which should be added somewhat, as Mr. Kidd's place is what in the West is commonly called a "road ranch," or a place where travelers may find food and lodging. Aside from the saving, there is the greater comfort and satisfaction of having fresh, clean vegetables instead of canned goods. This is a very important item, for herders willingly stay where food of this sort is furnished, while the problem of keeping help in the West is at best a difficult one. In summing up the value of the irrigation plant, Mr. Kidd thought that putting it conservatively it had increased the value of his ranch 15 to 20 per cent. At this ranch Mr. Kidd keeps upward of 10,000 head of sheep. At present he buys a large amount of hay from the better-watered country, but it is his intention to add to his irrigated area, by the construction of small reservoirs whenever an available site is discovered, until sufficient crops can be raised to avoid purchasing hay from others. Although wrapped up in the sheep business, he is greatly interested in farming and adds largely to local and State fairs by displaying the products of his land, which must be hauled 40 miles to the nearest railroad station. Last year at the Wyoming State Fair, by showing the produce raised on the 35 acres above described, he secured two first prizes and three second prizes.

M'DONALD RESERVOIRS.

Mr. McDonald has two reservoirs located about 6 miles northwest of the Kidd reservoirs and about 46 miles northwest of Casper. The two reservoirs are within a mile of each other in Spring Creek Valley, one of a series of small fertile valleys lying between the Big Horn Mountains and a very long, high wall running parallel with and along the base of the mountains, which is a very conspicuous landmark, being continuous for a distance of upward of 100 miles, with but three or four breaks in its entire length. These breaks are very narrow and have been made by streams bursting through this wall in recent geological time. They are holes in the wall, and the valleys above referred to are in what is commonly called the "Hole in the Wall" country, which not very many years ago was the rendezvous of the "rustler" and the outlaw, and around which many romantic and extravagant tales are woven. At the time of our visit, outlawry had long ago disappeared and instead thereof was a beautiful farm and range, the farm made possible through irrigation. Mr. McDonald is a large sheep owner and uses farming to supplement his range. Some irrigation is done directly from Willow Creek, which is a fine living stream. In the Spring Creek Valley, however, it is necessary to conserve the storm waters by storage reservoirs in order to irrigate, as Spring Creek is practically dry during the irrigation period save for occasional floods of short duration.

The smaller or Ryan Reservoir was built by Mr. Ryan in 1899 and subsequently purchased by Mr. McDonald. It lies farther down in the same stream than does the McDonald Reservoir, and now receives the surplus water from the latter. A dam was constructed across the stream at the lower end of what was a meadow bordering the stream. The area of the water surface when the reservoir is full is about 8 acres and the storage capacity is about 35 acre-feet. The dam is an earthen structure having a length of 400 feet, a top width of 10 feet, and a maximum height of 8 feet. The side slopes are both 1 on 1½, practically the angle of repose of the material used. This material is locally called red gypsum soil. It has a very brilliant red color, and contains a mixture of grit and clay in excellent proportions for dams, gypsum not being present in large enough degree to detract from its value. All the material used in the dam was taken from the wasteway and from within the reservoir, and was transported by means of horses and slip scrapers. The foundation for the dam was broken up with a plow before filling began, but it was not thought necessary to remove what plant life or other undesirable material there was from the foundation. Up to the present time leakage is imperceptible, but undoubtedly the organic matter will eventually decay, and whether leakage

will be serious depends upon the quantity of organic matter left in the dam. Because of the time of the year when the reservoir was constructed the earth used was as a rule sufficiently damp to pack well, and dependence was placed upon the tramping of the horses and placing the earth in rather thin layers.

The prevailing wind drives the waves obliquely against the dam, and to prevent damage the water slope was first riprapped with rocks weighing about 50 pounds laid directly upon the earthen surface. The rocks were hauled about a mile from the neighboring hills. This provision did not serve so efficiently as expected, the waves at times doing considerable damage. As a further expedient, willows have been planted on the water slope between the rocks. At the time of investigation they were still too small to be of any great service, although they have started quite thick, and if a good growth can be obtained and maintained they will break the force of the waves to a very considerable extent. Last year the accumulated damage from this source since the dam was completed was repaired, the work required, including the planting of willows, amounting to the use of three teams and three men for one week, which, together with tools, etc., is equivalent to an expenditure of $75, or at the rate of $15 per year. Expressed in other terms, the annual cost of maintenance has been at the rate of 43 cents per acre-foot of storage capacity. The cost of the completed structure was about $350, or $10 per acre-foot of storage capacity, giving an annual cost of maintenance of slightly over 4 per cent of the original cost.

The wasteway, excavated in solid material around the south end of the dam, has a width of 20 feet and a depth of 2 feet, which would seem rather small. So far, by opening up the outlet whenever the water has been dangerously high, damage has been avoided. With the construction of the larger reservoir above it, this danger is reduced to a minimum so long as the upper reservoir is kept in good repair. From the lower end of the wasteway the ground has a gentle slope and is well sodded, preventing erosion by waste water.

The outlet is located near the northerly end of the dam, and consists of 8-inch lap-welded pipe, piercing the dam at its base. The pipe does not extend through the entire dam, the water being brought to it by means of a trench extending about 8 feet into the dam and terminating in a well. The reservoir side of the well is open save for a timber frame which affords lateral support to its walls. The well is lined with a stone wall carefully laid up dry, with large regular stones. At its upper end the casing is fitted with a gate valve, the stem of which is manipulated from the curb of the well. This arrangement is very convenient, but it decreased materially the thickness of the dam at this place, so that water may penetrate the earthwork by traveling less distance than is ordinarily necessary, and the structure is corre-

spondingly weakened. An irregularity of this character in the slope of the dam makes it less able to withstand the action of waves than is one having uniformly sloping surface.

The upper reaches of Spring Creek are in comparatively rough rocky hills, showing, however, few signs of erosion, and there is little silt on the floor of the reservoir, after being in use for five years.

The water stored is used to irrigate 20 acres of alfalfa land lying half a mile below the reservoir. This land receives three good irrigations, beginning early in the spring, at each of which the reservoir is completely drained. There has always been ample water to fill the reservoir three times with a good margin to spare. Assuming that 30-acre feet are used at each irrigation, there would be applied annually, to the alfalfa, water to a depth of 4½ feet, or, with the precipitation, a depth of between 5½ and 6 feet. This is certainly ample, and doubtless the land would improve if this water were used to irrigate 30 or 35 acres of alfalfa in place of 20 acres. Last year 60 tons of alfalfa hay were harvested from this land, which enabled the owner to keep up 100 head of cattle, an impossibility without the reservoir.

Appreciating the value of this reservoir, Mr. McDonald looked about for another and larger site, with the result that at the time of the investigation the McDonald Reservoir, also on Spring Creek and three-fourths of a mile above the Ryan Reservoir, had just been completed.

The valleys before described as lying between the great wall and the mountains are usually separated only by a slight summit or saddle, the slope in either direction from which is gradual. The McDonald Reservoir is just to the northeast of one of these saddles which deflects Spring Creek to the northeast as it enters the valley. In making this change in direction a considerable basin has been formed, across the lower end of which a dam has been constructed, forming the McDonald Reservoir.

The area of the water surface with reservoir full is 15 acres, and the capacity about 75 acre-feet. The dam is nearly 500 feet long, has a top width of 15 feet, and slopes on the water side of 1 on 4 and at the rear of 1 on 2. Its maximum height is 12 feet. Mr. McDonald learned that steep slopes are very hard to maintain, and made his slopes in this case extraordinarily flat. It is a good fault, however, to err on the side of safety. The material which was used to build the dam is much the same as that in the Ryan Dam, the percentage of grit appearing to be larger in the McDonald Dam. The same kind of implements were used as were used in the smaller reservoir, and the same general method of prosecuting the work was followed. The reservoir had not yet filled, or even started to fill, at the time of investigation, so that it could not be determined just how well the dam

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would stand, but appearances were that everything about it was in first-class condition, and that the dam would give no trouble whatever. The work was all day work with the owner's teams, so there would be no object in not doing it thoroughly. The material used was borrowed indifferently from both sides and ends. Care was exercised to keep far enough away not to endanger the dam. The borrow pits were also shallow and of large area.

The slope was bare of wave protection, though it is Mr. McDonald's intention to pitch the inner slope in spite of its flat slope, because it is exposed obliquely to the action of the waves created by the prevailing winds. The rock for pitching must be hauled some distance, but probably the same course will be followed here as in pitching the Kidd Reservoir, utilizing the time of herders when they can be spared from the flocks, and skidding the rock down when enough snow is on the ground to make sledding easy. In this manner the cost will be very small. As the surface of the water slope is pitched it will also be planted with young willows, which are to aid in withstanding the waves.

The top of the dam is 3 feet higher than the saddle or summit above referred to, so that an ample natural wasteway is made available. The slope to the south from this wasteway is gentle and well sodded, and the valley widens as it leaves the wasteway, so that the surplus water will be wasted in a wide shallow sheet, creating little danger of erosion. The wasteway is an excellent one, for however large the flood it can in no way endanger the dam, and, were the McDonald Reservoir to be operated alone or independently, the site would be ideal. Surplus water turned southward through this wasteway, however, will not again find its way into Spring Creek, and therefore not into the Ryan Reservoir. The only way that the Ryan Reservoir can be filled after the larger reservoir is put into operation will be to run the water through the outlet of the McDonald Reservoir, for the catchment area of the Ryan Reservoir not tributary to the McDonald Reservoir is exceedingly small.

The outlet is an 8-inch lap-welded pipe. The trench and well, which were conspicuous features in the Ryan Reservoir, were omitted and the inner slope of the dam will therefore present a uniform and unbroken surface to the water. At its upper end the pipe will be fitted with an ordinary gate valve which will be regulated from a footbridge. The catchment area is the same as described in connection with the Ryan Reservoir, so that there need be no trouble with silt.

The stored water will be used to irrigate alfalfa, it being expected that 160 acres can be irrigated with the water from the two reservoirs. No estimate has been made as to how often the new reservoir will be filled. Even if great economy be practiced, it will be nec-

essary for both reservoirs to be filled and emptied at least three times each season to irrigate 160 acres of alfalfa. The catchment area is only about 3 square miles and it may not always produce sufficient water to fill both reservoirs three times, particularly if a heavy downpour occurs with the larger reservoir full and it is necessary to waste the surplus water to the south.

The cost of the larger reservoir will be in the neighborhood of $700, or a little over $9 per acre-foot of storage capacity.

BALLARD RESERVOIR.

The Ballard Reservoir is located within one-fourth mile of the Tisdale Reservoir, built by the Chicago and Northwestern Railway (see p. 30), about 30 miles northwest of Casper. Both reservoirs are cared for by Mr. Ballard, who has built up a general store, blacksmith shop, and post-office because of the attraction of these two bodies of water for sheep men en route for the market, and further, because the main highway extending into the country to the north of Casper passes directly between them. Through an arrangement with the railroad Mr. Ballard has the use of a certain portion of the stored water of the Tisdale Reservoir for keeping the reservoir in repair. Both reservoirs are used entirely for stock purposes. The capacity of the Ballard Reservoir is about 10 acre-feet. It receives the flood waters from a catchment area of about 1 square mile, which so far has been sufficient to fill the reservoir three times annually.

The same type of dam was used as that of the Tisdale Reservoir, with the important difference that no intercepting trench was excavated in the foundation and the grass was not removed. The material used was gumbo, in which there was sufficient alkali or other soluble salts to form considerable incrustation on the lower side of the dam where seepage was apparent. From the appearance and amount of this seepage it would seem that the construction was not so good as it should have been, though the bulk of the seepage probably occurs along the joint between the dam and its foundation. The material was nearly all borrowed from within the reservoir. The prevailing winds blow the waves away from the dam and no provision has been made for wave protection. So far no damage has been done from this source, and it is probable that none will occur. The cost of the reservoir was $500, or $50 per acre-foot.

A wasteway 15 feet wide and 2 feet deep was excavated around the south end of the dam, and though the waste water has considerable fall before reentering the creek, there is as yet no sign of erosion. The amount of waste water is probably never very great. The tributary catchment area is well covered with native grass sod,

with no signs of erosion, so that there is little danger from silt. As the reservoir is for stock purposes only, no outlet was provided.

It is stated that 30,000 sheep have been watered at the two reservoirs at Ballard at one time and that on an average 500,000 sheep are watered there per season. Mr. Ballard has installed a dipping plant, and because of this and other conveniences the place has become quite popular among sheep men as a shearing ground. As an investment Mr. Ballard places the value of the two reservoirs at upward of $2,000.

HEMMINGWAY RESERVOIRS.

Mr. Hemmingway's operations are in the southern portion of township 37 north, range 81 west, and about 5 miles south of the Ballard Reservoir just discussed. Mr. Hemmingway has constructed nine reservoirs, one of which is comparatively large and is used for irrigation purposes, while the other eight are small and are used for watering stock on the range. The stock reservoirs are distributed as opportunity occurs for a distance of 6 miles around headquarters. They average about 1 acre in surface area, with an average depth of not over 3 feet. Because of their size small tributary catchment areas are essential. In some cases steep banks occur on one of the sides of a reservoir and these banks have given a great deal of trouble because of the danger of drowning sheep and cattle in the deep water lying next to the bank or sometimes submerging it. The dams of these reservoirs have a top width of 6 feet, a water slope of 1 on 2, and a rear slope of nearly 1 on 1½. The material used in each case is gumbo, sometimes dry and sometimes damp, just as it happened to be at the time of construction. The material was put in place by ordinary slip scrapers and teams, the work being carried on as teams and men were available. The material was borrowed from whatever place seemed easiest of access. No attempt was made to deposit the material in layers or to compact the earth other than that accomplished by the horses in traveling over it. Because of this and because dry material was used in some places, contraction cracks occurred in a number of places, one of which was large enough at the surface to receive a man and extended for several feet in depth. Fortunately it was seen by a passer by, so that by strenuous effort the trouble was corrected before the water had gotten beyond control. Had it not been for this circumstance the dam would probably have been completely wrecked before it could have been known that anything was the matter. The waves formed on these small bodies of water have been too insignificant to guard against and though some of the dams receive the force of the waves direct no appreciable damage has been done.

The wasteway in each case is excavated around one end of the dam. The slope of the wasteway and that of the land lying below it is often rather great, but so far no erosion of consequence has taken place, probably because of the small amount of water that is wasted. The reservoirs have not been in operation long enough to demonstrate what may be expected in the way of silt, though the general appearance of the surrounding country would indicate that this may be a serious problem. However, as Mr. Hemmingway points out, if a reservoir becomes useless from this cause, it will cost very little to substitute another, the only real danger being that sheep and cattle may get mired in the silt. The aggregate cost of these eight reservoirs was not to exceed $500.

The large reservoir to be used for irrigation is located in a tributary of Casper Creek, advantage being taken of a basin in its bed. The site is a fair one and can be increased in size at some future day to advantage. The area of water surface when full is 12 acres, and the capacity of the reservoir is 65 acre-feet. The catchment area is about 12 square miles and would doubtless supply sufficient water for a much larger reservoir. The earthen dam has a top width of 10 feet, an inside slope of 1 on 3, and an outside slope of 1 on 2. A maximum height of 16 feet is attained for a short distance at the creek channel proper, the maximum height aside from this being 10 feet. The dam is 850 feet long with its highest part about the center. It has a bow downstream, which in its center is about 20 feet from a straight line joining its ends, this form being used to take advantage of the topography. For the most part gumbo was the material used, borrowed indifferently from above and below the dam, but good berms were left on each side of the dam. The material was put in place by means of slip scrapers and teams, the foundation being plowed before any earth was deposited. Grass and other organic matter, however, were not removed, nor was an intercepting trench made. Whether the dam is water-tight or not could not be ascertained, as the reservoir was empty and undergoing repairs and the borrow pits above and below were full of water, obliterating all evidence. The reservoir was in operation last year, and during the year there was a good deal of trouble from wave action. The prevailing wind, which is sometimes very strong, drives waves of considerable height directly against the dam. Although the water slope is flat, the waves reduced the cross section of the dam between 25 and 30 per cent in one year, and but for very rapid and dangerous work along its crest with hundreds of sacks of sand would have completely demolished it. As it was, the water was within 6 inches of topping the dam. This, as usual, was caused by an unexcepted storm of short duration but of abnormal intensity. At the time of inspection the repairing of the dam was nearly completed and Mr. Hemmingway was figuring

on some cheap, satisfactory wave protection. He had practically decided to try a combination of wire netting and sagebrush, building an erect fence of the netting and filling in behind with sagebrush and earth. This would give a terrace effect, confronting the waves with a sort of temporary revetment. This plan, with the substitution of wire netting for barb wire, is identical with that of Mr. Gray previously discussed (p. 51). The netting, unless exceedingly heavy, and therefore very costly, would not be so efficient as the barb wire because it rusts easily and would break from the force of the waves. Such expedients must be considered temporary, but they are within the means of struggling pioneers.

A wasteway with a bottom width of 30 feet was excavated around the westerly end of the dam, its bottom being but 2 feet below the top of the dam. At the time of the trouble above mentioned, there must have been in the neighborhood of 150 cubic feet per second running through it, and the floor should have been much lower and its width much greater to provide security to the dam. In no case should there be so small a difference in elevation between the top of the dam and the bottom of the wasteway, for, with the reservoir full and no surplus water to care for, such winds as prevail throughout the Rocky Mountain region could easily create waves high enough to completely deluge the top of the dam and imperil the entire plant. There is a fall of about 8 feet in the wasteway in a distance not exceeding 100 feet, and the water passing through the wasteway must attain great velocity and consequently great erosive power. Erosion at the lower end had already begun with the first year's use, creating a fall of a few feet in height near the lower end of the wasteway. With use, this fall will rapidly increase in height and size, and will recede toward the reservoir at an astonishing rate. Unless something is done to check it, the wasteway will become useless in a few years and will then be very difficult to rebuild.

In general plan the outlet of this reservoir resembles that of the Ryan Reservoir (p. 62), in that a trench is used as an approach to the outlet pipe, which in this case is a 6-inch, lap-welded pipe with a gate valve. The plans of the dam on file with the State engineer do not call for this trench, but show the pipe for the entire width of the dam. The trench extends into the slope about 15 feet and has nearly vertical sides held in position by plank sheeting. As pointed out in discussing the Ryan Reservoir, this is a source of weakness, especially dangerous in a case like the Hemmingway Reservoir, where the body of water is comparatively large, and exposed to a long sweep of wind directly against the dam. The plank sheeting is undesirable, as the planks will soon rot and be very difficult to replace, and the cracks between them will permit the entrance of water which will saturate the dam and be a source of weakness at the outlet, the very place

where effort should be made to give the structure additional strength. The entrance to the outlet is 2 feet above the bottom of the reservoir, so that the pipe is entirely within filled-in material. Even if the lap-welded pipe has sufficient strength to resist the crushing force of settling material, there is still great danger of voids occurring around the pipe, due to this settlement, forming channels for the water under a head of several feet to enter the dam and probably pass entirely through it. Once started, there is no telling to what extent damage may be done nor how great the loss of water.

There has been very little if any deposit of silt in the reservoir, as the catchment area is well covered with sod. However, the streams in the vicinity show signs of erosion, and some silting may occur.

The time consumed in building the large reservoir was equivalent to that of a man and team for 200 days, which, together with materials and tools, would mean an expenditure of $1,000, or at a rate slightly in excess of $15 per acre-foot of storage capacity. It is expected that the reservoir will fill twice during a season. At present there is 60 acres of land under irrigation devoted to alfalfa and potatoes. The stored water is to be used largely for raising hay for winter feeding sheep, and Mr. Hemmingway believes that by economy he can irrigate double the present area.

In the nine reservoirs that Mr. Hemmingway has constructed is worked out an admirable system of supplementing the range with irrigation from a flood-water reservoir. The eight small reservoirs make available for grazing a large body of range land otherwise too dry to be occupied except when snow is upon the ground. This range will provide pasture for 3,000 sheep for nine or ten months of the year without injury to the grasses. With irrigation from the large reservoir enough hay and fodder will be raised to winter feed the 3,000 sheep, which will not only eliminate the usual 10 per cent loss attendant on winter ranging, but will give increased wool production and weight. Using current prices of $4 per head, the saving of range losses for a single year will be little less than the entire investment for the nine reservoirs.

GARVEY RESERVOIRS.

Mr. O. K. Garvey owns two reservoirs, both located on the south fork of Casper Creek, in township 34 north, ranges 82 and 83 west, which is about 30 miles west of Casper on the main road leading from that city into the Shoshone Indian Reservation. The two reservoirs are within a mile of each other, the lower one being built first in 1900, by Mr. N. Schreiner. It is about three-fourths mile long and has an average width of one-fourth mile; the area of its water surface when full is 75 acres, and its capacity 435 acre-feet. South Casper Creek at this place flows through a small valley having a flat bottom and very

little fall. At a point where a rocky spur strikes into the valley from the hills on the southerly side an earthen dam has been constructed across this valley. The site is rather a favorable one, though the dam has a length of 1,000 feet, and is comparatively high throughout a large portion of its length. At the time of construction but little was known concerning the flow of the stream, and little judgment was shown in proportioning the capacity of reservoir and the size of the wasteway to that of the tributary catchment area. The catchment area is about 80 square miles in extent, and enough flood water to irrigate several thousand acres could be depended upon, and steps have been taken recently to store all the available water for the purpose of reclaiming lands under the "Carey Act." If this project is carried out, a large body of fertile land, which at present furnishes pasture for cattle and sheep for only a portion of the year, will be brought under cultivation.

The dam has a top width of 10 feet, a water slope of 1 on 3, and a rear slope of 1 on 2. The plans on file in the office of the State engineer call for a rock pitching on the water slope, though at the time of inspection, about five years after construction, there was no sign of any pitching. The plans also call for a masonry curtain wall 3 feet in height to be located immediately beneath the toe of the inside slope. The purpose of this curtain wall was to prevent saturation of the foundation of the dam, and interrupt seepage along the joint between the dam and its foundation, but it was impossible to determine whether this had been provided.

The material used in the body of the dam is a natural mixture of sand and gumbo in very fair proportions for dam construction, except that there is in the soil so large a percentage of soluble salts as to detract from its value for construction. Small scrapers and teams were used for the transportation of material, which was taken from borrow pits located both above and below the dam. There was sufficient berm left on either side of the dam so that the structure was in no immediate danger from that source, though a borrow pit below the dam is always a source of possible danger. Although the earth was well tramped by the horses, no precaution was taken to secure a bond between the foundation and the structure, the earth being filled in directly upon the undisturbed sod.

The prevailing wind strikes the dam at a very oblique angle, and little protection against wave action seems necessary. As above stated, pitching was called for in the plans and omitted in construction, but the surface of the inner slope had been crudely covered with cut brush held in place by pegs driven into the dam, some of which have taken root and grown. Up to the time of investigation no damage due to wave action was noticeable.

The wasteway was excavated through the rocky spur at the southerly end of the dam. It was given a bottom width of 10 feet, and its floor was 4 feet below the crest of the dam. Although the rock was not hard and was badly laminated, it was such as would be expected to resist erosion in a properly proportioned wasteway. This wasteway served fairly well, although used to the limit of its capacity and constantly a source of concern until the flood of 1904, which was augmented by the failure of the newly constructed reservoir above. During this flood it proved to be altogether too small, the water, which went through at a very high velocity, washing out large holes and depositing a great mass of the laminated rocks in the flat below. Even with the increase in the capacity of the wasteway, due to erosion, it was too small to pass the flood, and two sections of the dam were washed out, relieving the extraordinary high water in the reservoir. One of these sections is about 50 feet wide, and the other is about 20 feet wide.

The outlet of the reservoir is a 6-inch lap-welded pipe which pierces the dam at its joint with the foundation, where the dam has a maximum height. It has an ordinary gate valve at its upper end, the stem of which extends upward to a footbridge above high-water line. No provision was made to prevent seepage along the outside surface of the outlet, with the usual result. Silt has been deposited to only a very small extent in the reservoir, since the catchment area for the most part is well sodded and the remainder is covered with rock croppings.

About 1 mile above this reservoir there is a junction of two forks of South Casper Creek, and quite a valley extends for a considerable distance up each fork. Below the junction hills from either side protrude into the valley, making an ideal site for a dam and reservoir. About 1,000 feet south of the dam there is a very pronounced gap in the hills, forming a natural location for a wasteway far removed from the dam. At this place Mr. Garvey constructed his upper reservoir, which is much larger than his lower reservoir, and which failed during its first year's service. When full, it has a capacity of 1,000 acre-feet and the area of its water surface is 160 acres. The area of the catchment basin is upward of 75 square miles, the character of which has been described in connection with the lower reservoir. The dam is an earthen structure, having a top width of 10 feet, a water slope of 1 on 3, and an outer slope of 1 on 2. Its length on top is 900 feet and its maximum height 17 feet. The material used was a good natural mixture of gumbo and sand, though it appears to be very strongly impregnated with sodium or other soluble salts. This is apparently confirmed by the fact that directly above the dam there are a number of soda springs whose discharge is continuous and considerable in quantity. It is estimated that the material in the dam has upward of 10 per cent soluble

salts. The material was deposited on the top of undisturbed sod, with neither cut-off trench, wall, nor other provision to prevent seepage. All the material was taken either from the wasteway or from within the reservoir, the slope of the borrow-pit bank being very gradual and practically a continuation of the inner slope of the dam.

This dam occupied about the same exposure to the prevailing wind as the lower dam, but, because of the high hills on the northerly end of the dam, the wind is less severe. Protection from waves was not considered necessary, and no provision of the character was made. Knowing how readily the material is acted upon by water, Mr. Garvey expressed his intention of riprapping the water slope. The period of service of the reservoir was too short to observe any general effect of waves or water upon the unprotected slope.

As stated above, the wasteway was excavated through the gap in the hills about 1,000 feet south of the dam. The location of this wasteway was ideal in every way, for it provided a way to discharge the waste waters into another tributary of South Casper, with no chance of interfering in any way with the dam. Because the fall between the reservoir and this tributary is slight, the wasteway has an easy grade, eliminating the danger of excessive erosion. In order to provide a wasteway at this location, with the top of the dam at the elevation chosen, it was necessary to excavate to a maximum depth of 5 feet for a distance of about 500 feet. At the time of inspection the floor of the wasteway was only 18 inches below the top of the dam, though it is said that the dam has settled 18 inches since construction. It would therefore appear that the bottom of the wasteway was 3 feet below the top of the dam at the time of its completion. There are evidences that at the time of the failure the water stood 3 feet below the top of the dam and about 1½ feet below the bottom of the wasteway. Because of the great expense involved in making this wasteway serviceable, either by raising the dam or lowering the wasteway, Mr. Garvey has abandoned it, and has excavated another immediately south of the south end of the dam. Though cheaper in first cost because of its close proximity, this will be a source of constant danger to the dam and will add materially to the cost of maintenance. It would seem that after two failures all effort would be directed toward safety regardless of first cost. The bottom of the new wasteway is 8 feet below the present top of the dam, and is 30 feet wide. It has a length of about 200 feet, emptying into a small gulch that joins South Casper Creek immediately below the dam. In a very short distance the waste water must drop at least 8 feet, so that destructive erosion in the new wasteway is to be expected to begin very soon, to check which it will be necessary to install a structure at greater or less expense according to its character. When it has reached the

stage of successful operation, it will probably be found that it would have been best to deepen the original wasteway.

The outlet is a 10-inch lap-welded pipe, piercing the dam at its base. At its upper end it is fitted with a gate valve to be operated from a footbridge. No provision was made to secure water-tightness around the outlet pipe.

The dam failed at night, following a severe storm, the first providing sufficient run-off to store a large amount of water in the reservoir. The failure occurred near the original channel of the creek, leaving a gap about 50 feet wide. It is generally believed that failure was due to the extreme height of the water in the reservoir, which began washing a crevice at its top. Being new, there was a sharply-defined water line of small drift on the water slope of the dam, which indicated beyond doubt that the surface of the water in the reservoir at the time of failure was at least 3 feet below the top of the dam. In the bottom of the gap through the dam the original undisturbed sod was plainly visible. Taking all the evidence into consideration, it would appear that failure was due to the combined effect of several causes. Chief among these are, first, the fact that the earth was deposited directly on the original sod, giving no bond between the dam and foundation; second, the fact that the material of which the dam was constructed contained such a large percentage of salt easily susceptible to the action of water, which undoubtedly led to the rapid settlement of the dam and would permit of its being easily saturated; and, third, the fact that the bottom of the wasteway was not lower, which could not permit of relief to the reservoir until the dam would be on the verge of being overtopped.

Mr. Garvey, in spite of the discouraging breaks in both his reservoirs, began as soon as possible to repair the upper dam. His first efforts were directed to making the new wasteway above described. At the time of the investigation preparations were being made to repair the breach in the dam. The detritus and objectional material were cleared away and several trenches were excavated across the breach parallel with the axis of the dam. These trenches were 2 feet wide and about 2 feet deep, extending up both slopes of the breach to the surface of the dam. In all probability, by means of the trenches and removal of sod and detritus a good bond between earthwork and the foundation will be obtained. To successfully protect material of this character easily acted upon by water, and to insure its permanency, a casing of more resistant material, such as a proper proportion of grit and clay, should inclose the dam. This seems to be advisable in the case in question, unless there is better reason to locate and construct a new dam at some other point where the character of the material is better.

The combined storage capacity of these two reservoirs is 1,400 acre-feet, and the first cost to obtain this was $6,000, or at a rate of slightly less than $4.30 per acre-foot of capacity. It is estimated that to repair the dams will cost $1,500, or 25 per cent of the first cost. This could hardly be called maintenance, though it represents what is to be expected unless proper methods of construction and selection of material are followed at the start.

So far Mr. Garvey has irrigated 150 acres, one-half native hay and one-half alfalfa. This has been irrigated a number of years from the lower reservoir only, and when the upper reservoir is in service this area may be trebled. The average yield from the alfalfa has been 3½ tons per acre, while that of the native-hay land has been 2 tons per acre. Locally, the value of alfalfa hay is $10 per ton, and the value of native blue-stem hay is $17 per ton. At these prices there would have been a very good return on the investment even if we include the cost of repairs now in progress. Not all the hay was sold, however, as Mr. Garvey has used 100 tons of the hay to feed his 600 head of stock during the winter. Mr. Garvey asserts that, before irrigation, land in that vicinity was worth but $1.25 per acre, and the portion now irrigated has risen in value to $35 per acre. With increased irrigated area this value will rise still higher.

This completes the discussion of the reservoirs in the country around Casper, those following being near Newcastle, Wyo.

Newcastle lies at the foot of the western slope of the Black Hills, and but a short distance from the State line between Wyoming and South Dakota. The principal industry of Newcastle is mining, though large bodies of fertile prairie lands lie to the west, offering excellent agricultural opportunities which have been taken advantage of to a small extent only. This country is traversed by some of the tributaries of the Cheyenne River, chief among which is the Beaver Creek system. Little Beaver rises in the Black Hills and runs a very good stream of water nearly all the year. In the rolling prairie there are numerous sites for reservoirs which can be readily constructed at small cost and which will be supplied with sufficient flood waters to fill at least once annually.

SEDGEWICK RESERVOIR.

The Sedgewick Reservoir was constructed in 1899 and partially failed in 1900 and again in 1905. Nothing could be learned concerning the first failure, but the second will be discussed later. The reservoir is located in township 44 north, range 62 west, on one of the forks of Beaver Creek and about 10 miles southwest of Newcastle. This fork of Beaver Creek does not rise in the Black Hills; still it runs a large quantity of water at some times during the year. The catchment

area tributary to the Sedgewick Reservoir is about 75 square miles, its surface being for the most part rolling, grassy, and smooth, with occasional buttes. The area of the water surface of the reservoir when full is 50 acres, and its capacity 300 acre-feet. The site is a fair one for a reservoir, though it is very small in proportion to the size of the tributary catchment area.

The dam originally had a top width of 6 feet, a water slope of 1 on 2½, and rear slope of 1 on 1½. Its length on top is about 800 feet and its maximum height 14 feet. The material used was a combination of sand, loam, and clay naturally incorporated in such proportion as to make a fair material. At the northerly end there is a small amount of gravel which came from the borrow pit above the dam. The material was borrowed from both sides of the dam, a substantial berm being left below it. No special provision was made to secure a good bond between the dam and its foundation and the material when in place received no other packing than that due to the tramping of horses. As small slip scrapers were used, it is to be presumed that the effect of the tramping was considerable and well distributed.

The prevailing wind, at times very severe, blows directly against the dam, creating waves 3 feet high. As a protection from these waves, the water slope of the dam was covered with greasewood and rocks. The greasewood grows in small patches in the bottom of waterways and the rocks were hauled from hills several miles distant. The rocks were scattered with the brush to hold it in place. Posts were also driven at many places in the slope and brush fastened to them. After settling, the thickness of this coating is from 6 to 12 inches. Considerable trouble has been found in maintaining it, and constant attention and repair are required. In spite of this protection the waves have cut into the dam materially, and instead of the original uniform water slope of 1 on 2½, there is now a slope of 1 on 1 for a vertical distance of 5 feet beginning at the crest, after which the slope flattens to 1 on 5.

Around the south end of the dam a wasteway 25 feet wide and 3 feet deep was excavated. Successive storms had eroded the lower end of this wasteway to a small extent, the inevitable fall or drop in wasteways having steep slopes being present and working its way gradually toward the reservoir. To check this, a row of sand bags had been placed across the wasteway at the crest of this fall. On the 2d of July, 1905, with the reservoir full and all preparations made to begin irrigating, a severe storm occurred, which lasted for thirty-six hours. The storm was accompanied by a wind of great velocity, creating waves 3 feet high. The wasteway could not accommodate all the surplus water and the surface of the water in the reservoir steadily rose until the waves were pounding upon the very crest of the dam. The weakest point in the dam gave way, and before the storm had ceased a

gap 30 feet wide had been washed through at the original creek channel, cutting 4 or 5 feet below the original surface of the ground. It will cost about $300 to repair the breach in this dam, and if the season of 1905 had not been abnormally wet in this district, this amount would not nearly have covered the loss, for the crop dependent upon the reservoir would have been practically a complete failure. Aside from repairs to the dam, the wasteway should be entirely reconstructed. Its floor should be lower and its width should be at least doubled. Provision should also be made to protect it against erosion. All these things cost considerable at first, but are essential to the security of the structure, and will in the end pay.

The outlet is a 6-inch, lap-welded pipe piercing the dam at its base, with a valve on its upper end, regulated from a footbridge. There are signs of seepage at the lower end of the outlet, but the amount is inappreciable and will probably never give any trouble. However, considerable seepage loss has been occurring, and the only plausible explanation is that the gravel encountered in excavating for material, which reappears below the dam, extends under the dam and is a natural outlet through which the water escapes. The remedy for this is to determine the location and size of the gravel deposit and seal it at the upper end.

The silt accumulated in the reservoir in five years is only a thin skin, due to the fact that the surface of the catchment area is well covered with sod and composed of such materials as do not erode easily.

The original cost of the structure was $3,000. Repairs, including the break in the dam and reconstructing the reservoir, are estimated at $500, making a total outlay of $3,500. With the water from the reservoir there have been successfully irrigated 100 acres of alfalfa and 75 acres of native hay. The alfalfa has produced at the rate of 3 tons per acre and the native hay at the rate of 1½ to 2 tons per acre. The irrigated area will, therefore, yield about 425 tons of hay annually, the market price of which locally is $10 per ton, or a total of $4,250. The interest on investment, together with the cost of farming, irrigating, and preparing the land will amount to $1,750 yearly, yielding a profit of $2,500, a very good return on 175 acres of land and an outlay of $3,500 for irrigation plant. This plant, like most of the other private plants, is used to supplement the range. Through winter-feeding, the year before the break in the dam, Mr. Sedgewick was enabled to carry 7,000 sheep through the winter with practically no loss, where losses would have been 700 or 800 head. With the value of sheep at $4 per head, this loss would have been at least $2,800.

The land irrigated lies immediately below the reservoir in the valley of Little Beaver Creek. There is a good deal more land adjacent to

this which could be irrigated if the water were available. By raising the dam about 6 feet, the capacity of the reservoir could probably be doubled, and the tributary catchment area is large enough to fill the reservoir at least once a year.

WHOOP UP RESERVOIR.

The Whoop Up Reservoir was built by the MW Cattle Company, one of the few large cattle concerns still in existence in Wyoming. It is located on Whoop Up Creek, which is dry for nine-tenths of the year, but in severe storms rises rapidly and for a short period becomes a raging torrent. Just before Whoop Up Creek joins Little Beaver Creek in section 31, township 43 north, range 60 west, its bed opens up into quite a valley, closed at the lower end by hills on both sides. Through this valley the stream has but little fall and was converted into a reservoir by constructing an earthen dam connecting the hills above mentioned. Though application to the State engineer was made in 1896, the reservoir was not constructed until 1899. The catchment area of Whoop Up Creek is upward of 30 square miles, but this was considered insufficient to supply the necessary water and the bulk of the water was to be supplied by a ditch taken out of Beaver Creek, which has a good flow for most of the year. With these conditions the plan was a very good one. In 1900 there was a severe storm from which Whoop Up Creek received a large run-off and the reservoir began to fill very rapidly. When the surface of the water was about 10 feet below the top of the dam, and before it had reached the floor of the wasteway, the dam failed at the place where it crossed the old channel. Since then nothing has been done with the reservoir, though Mr. I. C. Jeffries, the manager of the MW Ranch, signified his intention of repairing it this year and making a new start. The cause of the rupture was probably poor workmanship and construction, for, though the application to the State engineer provided for puddling the central portion of the dam from top to bottom, there was no evidence in the walls of the breach of this having been thoroughly done, if it was done at all. The material used was a mixture of sand and gumbo in proportions which with puddling should have given excellent results. With the material put in place dry, the simple tramping of the horses would not be sufficient to give a solid, stable mass. That the mass was not packed solidly is shown by the fact that, although the plans show a difference in elevation between the top of the dam and the bottom of the wasteway of 4 feet, at the time of investigation this difference was only about 2 feet. This settlement is about what would be expected in a dry embankment. With water rising rapidly against the dry material, it is not surprising that failure took place at its weakest place, which, as in most cases, was at the original creek channel.

The dam has a length of 885 feet on top, a top width of 10 feet, a water slope of 1 on 3, a rear slope of 1 on 2, and a maximum depth of 29 feet. Material was obtained from both above and below the dam, as well as from the wasteway, but quite a berm was left next to the dam. The foundation of the dam was plowed before material was deposited, the material being moved by means of slip scrapers and teams.

Although the dam is sheltered and the prevailing wind drives the waves away from it, it was planned to riprap the water slope of the dam, stone of a rather poor quality being available near by. This riprapping was partially done at the time of failure, and has never been completed. The action of the waves will probably never be very great, though the ripples of the water alone affect a water slope of dry material. But if the mixture of gumbo and sand, free from soluble salts, be thoroughly puddled and compacted where exposed to the water, these ripples will have practically no effect.

A wasteway 50 feet wide was excavated through the hill at the south end of the dam. As above stated, the plans show the bottom of this wasteway 4 feet below the top of the dam, which it probably was when the structure was completed. A wasteway 50 feet wide and 4 feet below the top of the dam after settlement would seem to be ample for most of the time, but in case of violent wind against the dam with the reservoir full, would hardly prove sufficient. For the sake of safety, therefore, there should be a greater difference in elevation between top of dam and bottom of wasteway in a reservoir of this size. In repairing the dam it is intended to lower the wasteway. At the lower end of the wasteway the ground has a steep slope, and provision should be made to prevent erosion, which with a large body of waste water will be very great.

The outlet of the reservoir is an 8-inch lap-welded pipe, piercing the dam at the floor of the valley. No special provision was made to prevent leakage along it, and trouble from this source is to be anticipated if the reservoir is built. From the character of the catchment area it is not likely that there will be trouble from silt.

The capacity of the reservoir when full will be 1,300 acre-feet, the area of the water surface being 168 acres. The original cost is estimated at $3,500, and the necessary repairs to put the reservoir in operation are estimated to cost $450, making a total of practically $4,000, or something over $3 per acre-foot of capacity, which, even considering the unfortunate beginning, is a very low price for a reservoir of this size. The supply ditch to fill the reservoir is about 8 feet wide and 2 feet deep. It is simply an extension of the irrigation ditch used by the MW Ranch to take water from Beaver Creek. Just what portion of this ditch is chargeable to the reservoir is not known, but $1,500 would be a liberal allowance for it. This brings

the entire cost up to, say, $5,500, which is slightly in excess of $4 per acre-foot of storage capacity.

The water will be used to irrigate lands in the valley of Beaver Creek. From this reservoir at least 400 acres of alfalfa can be irrigated. The crop harvested from this land annually will amount to 1,200 tons, which, at $10 per ton, would be worth $12,000. Against this should be charged the interest on investment and the annual cost of irrigating and farming. At 6 per cent on $5,500, the former is $330, and the latter at $10 per acre will amount to $4,000. The total cost to produce a crop worth $12,000 is, therefore, $4,330, giving a profit of over $7,000 on 400 acres, or $17.50 per acre. This is certainly a handsome return on the investment. Mr. Jeffries is irrigating about 1,000 acres in the Beaver Valley from the normal flow of Beaver Creek, the produce from which is used to feed stock during the winter, permitting the raising of very large herds with practically no loss. It is presumed that the produce from the lands irrigated by Whoop Up Reservoir will be fed in the same manner. The loss of his neighbors, who do not winter feed, is placed at not less than 10 per cent.

EDGEMONT RESERVOIR.

This reservoir is one of the very few private reservoirs of its class which had engineering supervision during construction and which shows careful thought in design. The reservoir itself, like the Whoop Up Reservoir, is away from the stream furnishing the water supply. Unlike this reservoir, however, its tributary catchment area is very small. On the westerly slope of a low range of hills, just below their crest, was a saucer-shaped valley inclosed except at its lower side. A dam on this lower side completed the rim and an excellent storage reservoir was created. It is located in section 18, township 42 north, range 60 west, about 20 miles southeast of Newcastle. The reservoir is filled from Beaver Creek by means of a supply ditch several miles long. Because of the small catchment area tributary to the reservoir itself, the supply of water can be regulated to a nicety and no complications will arise such as confronted the owners of the Whoop Up Reservoir when a heavy storm occurred. Application for permission to construct was made in March, 1896, soon after which actual work began. The area of the water surface with reservoir full is 120 acres, and the capacity of the reservoir 1,405 feet. The earthern dam has a length on top of 1,100 feet, a top width of 10 feet, water slope of 1 on 3, and rear slope of 1 on 1½. Its maximum height is 32 feet. There is an intercepting or puddle trench 10 feet wide and 3 feet deep, cut into the foundation along the axis of the dam, which serves as a foundation for a puddle core ranging in thickness from 10 feet to 5 feet and extending from the bottom to the top of the dam.

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The material used for the dam is a mixture of gumbo and sand in fairly good proportion, selected material being used for the core. The material was moved by slip scrapers and teams, the surface being always kept concave for the purpose of puddling the center, water being furnished through the supply ditch. The remainder of the dam received only the compacting due to the tramping of horses, though undoubtedly the water used in puddling spread laterally to considerable extent. Before the fill was begun the foundation was carefully and thoroughly plowed and all unsuitable material removed. The work was carried up in a series of benches, there being approximately 8 feet difference in elevation between consecutive benches. Material was borrowed from both above and below the dam, the maximum depth of borrow pits being 4 feet, and berms of 25 feet being left between the toe of the slopes and the borrow pits. The slopes of the borrow pit banks were in no case steeper than 1 on 3. These provisions regarding the borrow pits are good ones and safeguard the dam against danger from this source. Though in service for seven years, very little settlement has taken place in the dam, a few spots on the rear slope only showing signs thereof.

Although the prevailing winds do not beat directly upon the slope of the dam, provision was made to face the slope with 1 foot of gravel. In reality, pieces of sandstone 6 to 8 inches in diameter were used, being well laid on the slope. The stones are not durable and many of them are disintegrating badly where they have been in contact with the water for a number of years. At the time of investigation the surface of the water was about 12 feet below the top of the dam, around which elevation it has fluctuated only a few feet for the past four years. As the result of this nearly constant position of the water surface, a nearly vertical bank 3 feet high has been made in the inside slope, at the foot of which the slope is 1 on 6 for 6 feet, after which the original slope of 1 on 3 appears to be maintained to the foundation. This bank is in itself not a very serious matter, as the pitching above it has not been disturbed and will probably serve with a small amount of repair, until the rock disintegrates.

The outlet is a 16-inch cast-iron pipe laid in a trench 2 feet below the foundation surface, the only case found during the investigation where this was done. In this manner the danger of crushing or displacement due to settlement of the filled-in earth is eliminated. At intervals of 20 feet intercepting wings or collars are fitted around the pipe to prevent seepage along its outside surface. The wings were of planks and extended for a distance of 2 feet all around the pipe. After the pipe was laid the trench was refilled, care being taken to pack the earth well around it. At both ends of the outlet small masonry head walls were provided, which afforded support to the ends

of the pipe and kept the entrance and exit free from falling earth. The upper end of the outlet pipe is fitted with a brass-lined gate valve having all moving surfaces of brass. Iron or steel surfaces would corrode and soon adhere so firmly that the gate could not be operated. The stem from the gate extended upward, to be operated from a footbridge. Prior to the time of inspection, the stem had been broken off below the then surface of the water. Inquiry concerning the cause of this elicited different answers. One was that the stem and bridge had been destroyed by ice and drift during a storm. Another was that it was broken through the ignorance of an operator, the bridge being taken away piecemeal by passers by. Still another, that the valve, after being disused for several years, stuck tightly and that the stem was broken in an endeavor to open it. The last seems improbable because of the construction of the valve.

A wasteway was excavated through a low place in the rim of the reservoir about 500 feet south of the dam. It was made 25 feet wide, with its bottom 4 feet below the top of the dam. In excavating a maximum depth of 5 feet was reached. The water wasted can not come in contact with the dam, as there is a spur of hills between them. Because of the very small catchment area, the level of the reservoir can be accurately regulated, and a very small wasteway will suffice. The bottom of the wasteway would seem to be too high, leaving a very small free board for a dam of its height with so large a body of water impounded behind it. To be sure, little damage is to be anticipated from waves created by the prevailing winds, but should an easterly wind of high velocity occur with the reservoir full, on a body of water of this expanse, it might create waves 4 feet high which would sweep the crest of the dam, doing great damage.

Notwithstanding the great care that was taken, there are signs of considerable seepage below the dam, such as the presence of tules and the efflorescence of alkali and other soluble salts on the surface of the ground. It is hard to believe that leakage through the dam would be sufficient to cause this, and it may be that leakage is occurring through gravelly or porous strata lying below the intercepting trench, as gravelly deposits occur in several places within the reservoir. This can be ascertained only by exploration, which is absolutely essential in a dam of this height. It is not that the loss of water is so great, but that saturating the foundation and the soil downstream from the dam weakens it.

The reservoir was built by the Beaver Creek Irrigation and Canal Company for the purpose of irrigating land in the valley of the South Fork of Cheyenne River and its tributary, Beaver Creek, lying north of Edgemont, S. Dak. The position occupied by the reservoir is a commanding one, and by filling but once yearly between 600 and 700

acres could be thoroughly irrigated. Soon after construction it was filled to high- water line, the bottom of the wasteway. Since then the reservoir has been tied up in controversy and litigation, its service ending soon after it began. This is to be regretted, for had it been in use it would have been an excellent object lesson which would have contributed largely to the development of that portion of the State. It would seem that there would be some process of the law whereby such retarding influences in the development of fertile land, so easily accessible and reclaimed, could be stopped.

Following is a tabulation summarizing the various elements of the reservoirs constructed in the prairies by private enterprise, which have just been discussed.

Private reservoirs on the prairies.

Name.	When built.	Dam.					Outlet.	
		Maximum height.	Top width	Top length.	Water slope.	Outer slope.	Kind.	Size.
		Feet.	*Feet.*	*Feet.*				*Inches.*
Oliver	.....	8	4	200	1 on 1½	1 on 1½	Wooden box..	8 by 8
Brant	1900	8	8	350	1 on 2	1 on 1	.....do.....	.....
Harris No. 1	1900	12	6	175	1 on 1½	1 on 1½	.....	.....
Harris No. 2	1904	12	6	500	1 on 3	1 on 1½	Wooden box..	6 by 12
Harris No. 3	1905	.....	.....	.....	.....	.....	.....	.....
Gray (5)	1905	15–20	10	100–150	1 on 3	1 on 1½	Wooden box..	.....
Barbour (3)	.....	12	10	100–150	1 on 2	1 on 1½	.....do.....	.....
Kidd	1903	20	12	200	1 on 3	1 on 2	Lap-welded pipe.	7
Warner	1903	16	10	110	1 on 3	1 on 2	.....do.....	6
Ryan	1899	8	10	400	1 on 1½	1 on 1½	.....do.....	8
McDonald	1905	12	15	500	1 on 4	1 on 2	.....do.....	8
Ballard	1904	.....	.....	.....	.....	.....	None	.....
Hemmingway	1904	16	10	850	1 on 3	1 on 2	Lap-welded pipe.	6
Garvey No. 1	1898	14	10	1,000	1 on 3	1 on 2	.....do.....	6
Garvey No. 2	1904	17	10	900	1 on 3	1 on 2	.....do.....	10
Sedgewick	1900	14	6	800	1 on 2½	1 on 1½	.....do.....	6
Whoop Up	1899	29	10	885	1 on 3	1 on 2	.....do.....	8
Edgemont	1896	32	10	1,100	1 on 3	1 on 1½	C. I. pipe.....	16

Name.	Wasteway.		Capacity.	Area.	Average depth.	Original cost.		Area irrigated
	Depth.	Width.				Total.	Per acre-foot.	
	Feet.	*Feet.*	*Acre-feet.*	*Acres.*	*Feet.*			*Acres.*
Oliver	.....	.....	10	4	2.5	$200	$20.00	10
Brant	4	.....	60	15	4.0	200	3.33	50
Harris No. 1	Natural.		10	3	3.3	80	8.00	[a] 1½
Harris No. 2	4	.....	85	20	4.2	500	5.88	150
Harris No. 3	.....	.....	100	25	4.0	750	7.50	
Gray (5)	Natural.		60	12	5.0	900	15.00	.....
Barbour (3)	.....	.....	25	7	3.5	250	10.00	20
Kidd	5	40	60	8	7.5	2,000	33.33	35
Warner	4	10	16	2	8.0	400	.....	.....
Ryan	2	20	35	8	4.4	350	10.00	20
McDonald	Natural.		75	15	5.0	700	9.33	.....
Ballard	2	15	10	.....	.....	500	50.00	[b]
Hemmingway	2	30	65	12	5.5	1,000	15.00	[c] 60
Garvey No. 1	4	10	435	75	5.8	6,000	4.30	150
Garvey No. 2	8	30	1,000	160	6.3			
Sedgewick	3	25	300	50	6.0	3,000	10.00	400
Whoop Up	4	50	1,300	168	7.7	3,500	2.69	.....
Edgemont	4	25	1,405	120	11.7	.....	.....	.....

[a] Also used for domestic purposes.
[b] Used for watering stock.
[c] Does not include 8 small reservoirs.

CONCLUSIONS.

It appears from this investigation that the future development of the cattle and sheep industries in the Western States will lie along the line of better care of stock, in this way increasing the number and quality of animals that may be maintained. It is generally acknowledged that open ranging reached its limit sometime ago. With the gradual decrease in the range area, due to overpasturing and settlement, the old system of continuous ranging must be abandoned and the range supplemented with the farm. In this district successful farming can be done only by means of irrigation or a combination of so-called dry farming and irrigation. Irrigation so far has been practiced principally from large water supplies, little having been done toward conserving and developing small water supplies. Even by developing the small water supplies but a small portion of the land still available for settlement may be irrigated. It is firmly believed that no plan for the settlement of the dry prairies will be successful unless there be a combination of reclamation by irrigation and pasture. Through the desert-land act a settler may obtain title to only the land reclaimed, with 320 acres as a maximum. He receives no title whatever to pasture lands adjoining nor can he always lease it. His use of it, therefore, will cease at any time a settler may take it up. It is well known that an acre of good farming land will produce sufficient hay to keep at least 20 head of sheep for a 90-day period in the winter, whereas, on the best of range pasture, no more than one head per acre can be counted on. Because of the nature of these unirrigated prairies and the comparatively small value of their product, one can not make a comfortable living on such small pieces of land as are usually considered sufficient in more favored localities, particularly when a large share of it is range pasture. In order that the dry prairies may be settled with good thrifty homes, the settler should have as much as two sections, or 1,280 acres of land. Of this, 60 acres should be well irrigated and farmed and the remaining 1,220 acres should be pasture land and reservoir from which practically all the irrigation would be accomplished, and it is believed that in every two sections of land in the prairies there may be found one or more reservoir sites sufficient to irrigate 60 acres. This gives the desired ratio of about 20 acres of pasture land to 1 acre of farming land. To show that such an arrangement would be profitable, the following is presented:

It is assumed that the farming land produces alfalfa hay for feed. Sixty acres of alfalfa will require ordinarily about 180 acre-feet of water during the year, provision to supply which must be made. From this investigation it appears that these small reservoirs, as a rule, fill twice during the year. The reservoir in this case, however,

we will consider fills but once a year, and that its capacity is therefore 180 acre-feet. By reference to figure 5, p. 27, it will be seen that the probable cost of a reservoir of this size will be $8 per acre-foot of its capacity, or a total of $1,440. To this should be added the cost for outlet ditches, etc., a liberal allowance for which would be $500, making the total investment for irrigation plant, say $2,000. The annual cost would therefore be:

Interest on investment at 6 per cent	$120.00
Repair	50.00
Farming 60 acres, at $5	300.00
Total	470.00

At 4 tons per acre, the hay from 60 acres would supply 4 pounds of hay per day for 100 days, to 1,200 head of sheep. The annual benefits derived from winter feeding would be:

5 pounds increase in weight per head, at 4 cents, on 1,200 sheep	$240.00
1 pound increase in wool per head, at 15 cents, on 1,200 sheep	180.00
Saving of 10 per cent, usual winter range loss, 120 head, at $4	480.00
Total	900.00

This shows a net profit of $430 from winter feeding, or a return of over 20 per cent on the investment. This estimate does not include the value of vegetables which are raised and consumed at the farm, and ice which is stored and used later for refrigerator purposes, upon which it is hard to put a value. It is probable that these two items represent upward of $100, though the ranchman who has had the benefit of them would not be dispossessed of them for many times this amount.

During this investigation the writer was impressed with the lack of knowledge on the part of some of the settlers concerning the fundamental principles of reservoir construction, and he was more impressed with the very few opportunities for the settler to obtain this, as well as with the intense eagerness of the settlers in their endeavors. The pity is that such hard, honest work should not have the benefit of intelligent advice and supervision. From observation it is firmly believed that advice given freely by the Government officials will be gladly received and freely followed. Great mistakes are being made by settlers every day which will some time cost them dearly.

AVAILABLE WATER SUPPLY.

Taking Wyoming as a fair example of the stock-growing States, it is found that the average annual precipitation in the State is 13 inches in depth, or, expressed in quantity, 68 million acre-feet, of which 2½ million acre-feet are used in irrigating directly from rivers and streams, one-half million acre-feet are used to supply storage reservoirs, 11 million acre-feet pass out of the State in the various

rivers, and 54 millions are either lost through evaporation or absorbed by the soil to pass out of the State as underground waters. The disposition of the available water supply is shown graphically in figure 10. Of these various quantities, that of 11 million acre-feet which now passes away unused is available for storage in small reservoirs. Were this water all conserved it would be sufficient to irrigate about 4 million acres, or about one-fifteenth of the entire area of the State of Wyoming. At present the total area in Wyoming irrigated from all sources is something less than 1 million acres. From this analysis it also appears that if every drop of available water be utilized there will yet be ample range land to be used in connection with the irrigated areas.

Having shown in general terms the feasibility of irrigation from small water supplies, attention will now be given the problems that the settler must solve in constructing and maintaining small reser-

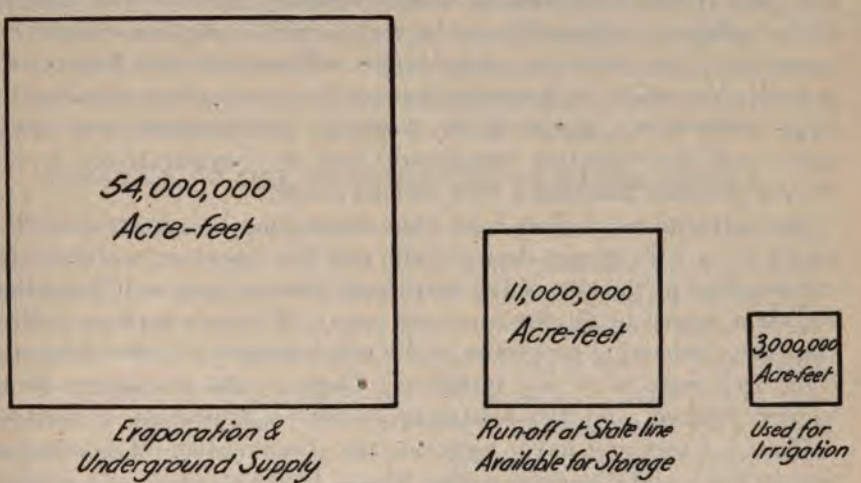

FIG. 10.—Disposition of precipitation in Wyoming.

voirs, which may be enumerated as follows: (1) Selection of reservoir site; (2) size of reservoir and water supply; (3) design and construction of dam, including wave protection for dam, and outlet; (4) wasteway; (5) accumulation of silt, and (6) loss from seepage.

SELECTION OF RESERVOIR SITE.

In the rolling prairies there are very many reservoir sites available, but careful search is often necessary to reveal them. Exceptionally good sites with a low cost of storage are usually readily recognized. Because of the character of our prairie region, most of the reservoirs will be built on so-called dry streams in which water runs only during and just following storms.

These reservoirs may be divided into two general classes: (*a*) Those constructed in the bed of the stream from which they receive their water supply, and (*b*) those that are not constructed in the bed of the stream from which they are supplied but which receive their water through supply ditches, conducting water from independent catchment areas. Class *a* has the advantage of being in position to catch all the water that comes from the catchment area lying above it, and the further advantage that the expense of a supply ditch is obviated. If the water carries a low percentage of sediment, this class of reservoirs will become practically water-tight through the deposit of fine silt, which will enter and fill the pores of the soil in the floor of the reservoir and form a compact skin of finely divided particles.

The disadvantages of this class of reservoirs are that the proper ratio between reservoir and catchment area should be had to obtain the best results, and this is often extremely difficult and costly. If the tributary catchment area be very large in comparison with the capacity of the reservoir, great danger will attend each freshet, to provide for which it becomes necessary to construct abnormally large wasteways. Again, if the water be heavily laden with sediment and the tributary catchment area be comparatively large, the silt problem becomes a very serious matter.

The advantages of class *b* are that water may be admitted to the reservoir at will, at any desired rate, and the reservoir is absolutely independent of the size of the catchment area so long as it furnishes sufficient water to fill the reservoir once. With a reservoir of this class the silt-bearing properties of the water are not a matter for concern, and there is no silt problem. There is also no danger from sudden freshets and the wasteway is not so important a matter.

Class *b* reservoirs have, however, the disadvantage of needing a supply ditch and diversion works, which, however small, add largely to the cost of the plant, as well as to that of maintenance. There is also the disadvantage of not being able to benefit by storing all the water of freshet floods without making the size of the supply ditch beyond reason. This is a serious fault in the prairie region, for the flood waters usually occur in large bodies of short duration. Another disadvantage is that reservoirs of this class are as a rule subject to considerable seepage, and, as all silt in the water is deposited before it reaches the reservoir, the water does not furnish sediment to fill the pores of the soil in the bottom of the reservoir, and other and more costly methods of prevention must be resorted to. Still another disadvantage is that, because of the slowness with which ice disappears in the spring in the ditches, storage can not be begun so early in this class of reservoirs as in reservoirs of the first class.

These advantages and disadvantages should be given careful consideration in deciding upon a site, though by far the large majority of sites available are of the first class. It would seem that the relation between reservoir and catchment area should be such that the latter will supply sufficient water to fill the reservoir at least once and not more than twice yearly. In addition to this, for a good reservoir site there should be a comparatlvely broad flat valley, having very little slope in the direction of the stream. Advantage should be taken of natural topographical features that will decrease the length and height of the dam and increase the impounding basin. There should be opportunity to provide ample wasteway, preferably entirely apart from the dam. If there be choice in position relative to the prevailing wind, the one where it blows waves away from the dam should always be chosen. As a rule, however, there is little choice in this matter, it being largely determined by the general trend of the country. A good reservoir site should have a firm foundation for the dam and ample material of good quality easily available. The reservoir should be located so that but a short distance separates it from the land to be irrigated, for, aside from ditches being costly, the loss of water in them from seepage is often very great.

RELATION OF SIZE OF RESERVOIR TO WATER SUPPLY.

Taking the total precipitation and run-off at the State lines (fig. 10, p. 85) and assuming that half of the water used direct from streams and stored for irrigation is included in the run-off as return seepage waters, we find that with a precipitation of 68 million acre-feet we have a run-off of 12½ million acre-feet, or 18.38 per cent. These being the best available data concerning run-off and precipitation in this region, it is assumed that for the purpose of yielding water the average run-off is about 18 per cent of the precipitation. Being obtained from measurements of large catchment areas, this result does not hold strictly for small ones, the error on the whole being on the side of safety. While the results worked out here represent average conditions, because definite data are not available under other conditions, it must be borne in mind that the result may vary considerably for other conditions, a difference of several per cent in either direction being probable for either good or very poor catchment areas. Therefore, with an average annual rainfall of 13 inches, the run-off available for storage (neglecting evaporation) would be equivalent to a depth of 2.34 inches over the entire catchment area, or under average conditions the extent of the catchment area in acres should not be less than five times the capacity of the reservoir in acre-feet. Considering losses of evaporation and probable differences in conditions, this ratio had best be 10. This of course is to be used solely as a basis to work

upon and should be changed according to local conditions. The occurrence and rate of run-off is dependent largely upon the intensity of storms, which in turn varies inversely as their duration—that is, much greater intensity is found in storms of short duration than in those of long duration. The percentage of run-off is materially affected by the intensity of the storm, it reaching in some cases 30 per cent for short, sharp storms. Through the courtesy of W. S. Palmer, section director of the U. S. Weather Bureau for the State of Wyoming, it has been possible to compile the rainfall record throughout the State, the bulk of the data for short storms being those recorded at Cheyenne by a tipping rain gage. The stations are typical ones and the lengths of records vary from five to thirty-five years, and, while it is realized that the longest of these periods is but short, it is also realized that some such information is very necessary just at this time, the beginning of the era of small reservoirs, and in years to come these data will form the basis for other and more reliable deductions.

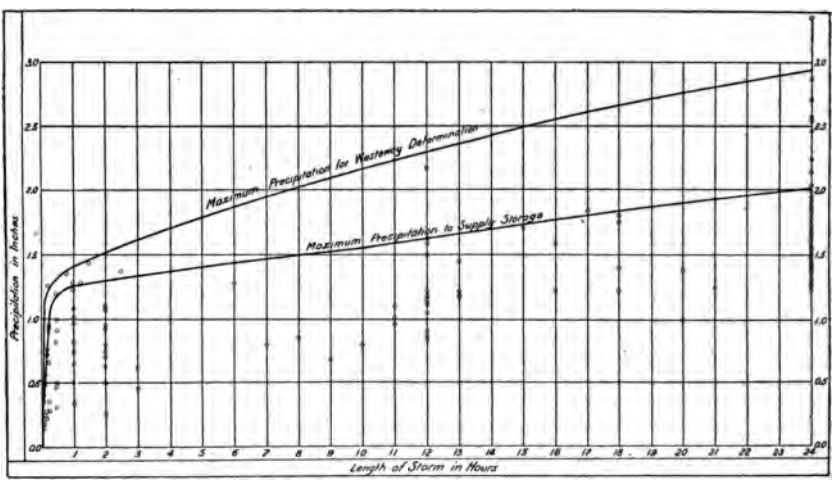

FIG. 11.—Diagram showing maximum precipitation for storms of different lengths.

From these data the diagram shown in figure 11 has been constructed. Two lines are shown, the lower representing the maximum precipitation for storms up to twenty-four hours' duration to be considered available for storage purposes at 100 per cent run-off, and the upper line the maximum precipitation, under same conditions, to be used in estimating the capacity of wasteway. While the increase from two hours to twenty-four hours is reasonably uniform, that for storms less than two hours is not at all so.

To estimate the run-off available, the percentage factor must be applied to the values taken from this curve. For storms of two hours or over, the factor will ordinarily be between 15 and 18 per cent. By combining good judgment with the results of these curves fairly close results may be secured.

Since the water supply controls also the size of the wasteway, it seems best while on that subject to discuss the relation between run-off and wasteway, leaving the matter of construction and protection to be treated later (p. 92). If 100 per cent of the rainfall ran off its volume in cubic feet per second per acre would be numerically equivalent to the rainfall in inches per hour. We therefore used this rate of precipitation in inches per hour to express the intensities of storms. The maximum precipitation in a ten-minute storm is 0.77 inch. Therefore, the intensity of such a storm, expressed as indicated, is $6 \times 0.77 = 4.62$ inches per hour, and the run-off at 100 per cent is 4.62 cubic feet per second per acre. Line *B*, in figure 12, indicates the maximum intensities of storms from five minutes to two hours'

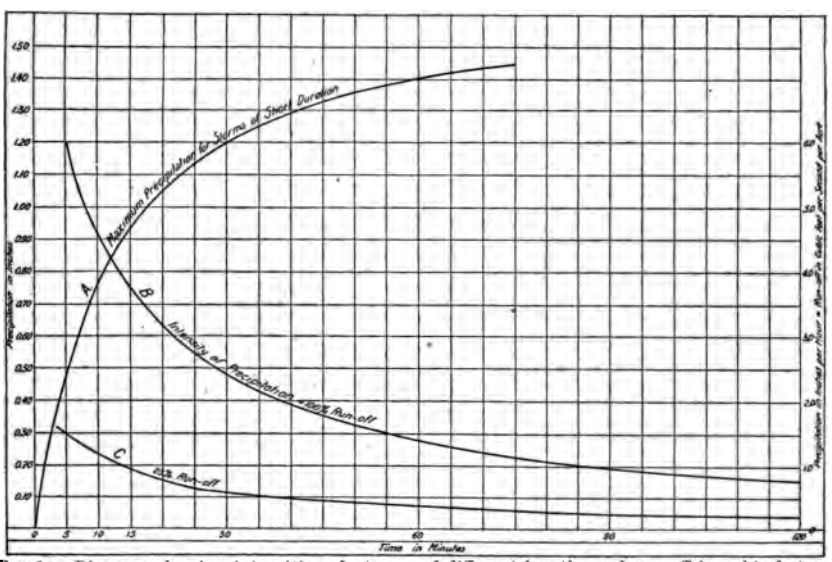

FIG. 12.—Diagram showing intensities of storms of different lengths and run-off in cubic feet per second per acre.

duration, which is also 100 per cent of the run-off for these storms in cubic feet per second per acre. As much of the precipitation is lost in evaporation, seepage, etc., we never get 100 per cent. The percentage that does run off varies for storms shorter than two hours according to character of slope of catchment area, degree of saturation, and length of storm. With the catchment area well saturated it varies from about 18 per cent for two-hour storms to about 30 per cent for five-minute storms, though this variation is not uniform. A fair average for storms of the character under discussion would be 25 per cent. This is represented by line *C*, figure 12. On page 90 are tabulated the length of storms, maximum precipitation, intensity, and run-off.

Intensity of storms of different lengths, and run-off from the same.

Length of storm.	Precipitation		Run-off per acre at 100 per cent.	Run-off per acre at 25 per cent.
	Amount.	Rate per hour.		
Minutes.	*Inches.*	*Inches.*	*Cubic feet per second.*	*Cubic feet per second.*
5	0.50	6.00	6.00	1.50
10	.77	4.62	4.62	1.15
15	.94	3.76	3.76	.94
30	1.20	2.40	2.40	.60
60	1.40	1.40	1.40	.35
90	1.47	.98	.98	25
120	1.52	.76	.76	.19

To illustrate the use of these diagrams, a concrete case will be taken, as shown in figure 13. Here we have a problem presented in South Dakota. The dam and wasteway are located at *B*, from which point the catchment area extends to the left inclosed within the dotted line. The distance from *B* to the most remote point in the watershed is 3 miles, and that from *A* to the most remote point of the watershed above it is 1 mile.

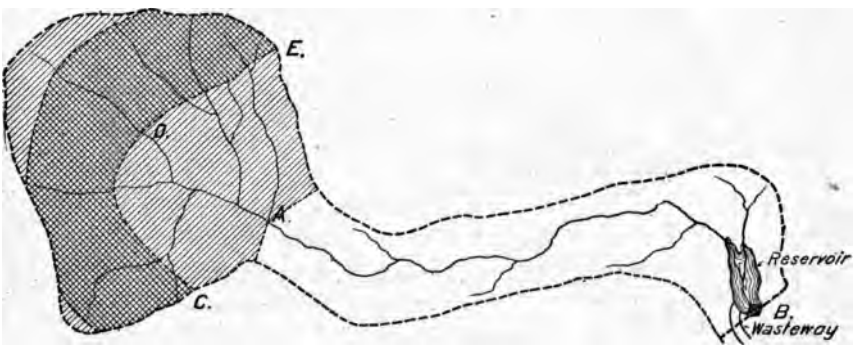

FIG. 13.—Map of a reservoir site and its catchment area in South Dakota.

The cross-hatched area lying above the line *C D E* is the maximum area delivering run-off from a storm of fifteen minutes' duration. In other words, if we have a fifteen-minute storm over the upper portion of the catchment area, run-off water starting at the upper edge of this area and traveling at a speed of 2 feet per second will reach the line *C D E* by the end of the storm, so that the waters in the different streams within this area will reach *A* simultaneously and be carried in a body to the wasteway. That that is the maximum area operative during a fifteen-minute storm is seen by inspection. The entire catchment area is 1,040 acres, the catchment area above *A* is 640 acres, and that of the cross-hatched area above the line *C D E* is 320 acres. Assuming a speed of 2 feet per second, it will take run-off water starting from the most remote part of the watershed one hundred and thirty-two minutes to reach *B*, which means that for the entire catchment area to be operative there must be a storm whose duration is one hundred and thirty-

two minutes. Similarily, for all that portion of the catchment area above *A* and no more to be operative there must be a storm whose duration is forty-four minutes.

Referring to the upper curve in figure 11, we find that the maximum rainfall in a storm with a duration of one hundred and thirty-two minutes is 1.53 inches, or an intensity of 0.70 inch per hour, which gives us a run-off of 0.70 cubic foot per second per acre. Using a factor of 25 per cent, the discharge at the wasteway, with 1,040 acres operating, will be 182 cubic feet per second.

Assuming the same speed of 2 feet per second, it will take run-off water forty-four minutes to reach *A* from the edge of the catchment area above. We have, therefore, to consider a storm whose duration is forty-four minutes in determining the run-off with all of that portion above *A* delivering run-off. Referring to curve *A*, figure 12, we find that the maximum rainfall for a storm of forty-four minutes' duration is 1.33 inches; from curve *B*, same figure, we find its intensity to be 1.82 inches per hour, and the run-off at 100 per cent, 1.82 cubic feet per second per acre. Using a factor of 25 per cent with 640 acres operating, we have a discharge at *A*, and therefore at the wasteway, of 291 cubic feet per second.

Now, considering the annular area of 320 acres above the line *C D E*, we have a storm of fifteen minutes' duration. By referring to figure 12, as in the previous instance, we find that the maximum intensity of a fifteen-minute storm is 3.75 inches per hour, and that at 25 per cent the run-off at the wasteway is 300 cubic feet per second; all these results are tabulated as follows:

Capacity of wasteway necessary for storms of different lengths.

Length of storm.	Intensity of storm.	Catchment area delivering run-off.	Run-off—	
			Per acre (100 per cent.)	At wasteway (25 per cent).
Minutes.	*Inches per hour.*	*Acres.*	*Cubic feet per second.*	*Cubic feet per second.*
132	0.70	1,040	0.70	182
44	1.82	640	1.82	291
15	3.75	320	3.75	300

In the above discussion the regulating influence of the reservoir has been neglected, as has also the lengthening of the short-storm flood wave between *A* and *B*. In small reservoirs with small catchment areas, these two items enter to such a small degree that we are warranted in neglecting them.

From this table the influence of short storms on the size of the wasteway is apparent. That failure to recognize this has resulted disastrously is shown by the remarks often made in connection therewith, that the storm causing it, though severe, was short, and extended over only a portion of the catchment area.

DESIGN AND CONSTRUCTION OF DAM.

The success of an earthen dam depends about equally on design, method of construction, and material used, though for dams not over 12 feet high it is not so important that the material be the best, nor that such great care be used in construction. As a rule, however, the one who uses best methods and materials is well repaid for his trouble. From this investigation it appears that while pure gumbo has in most cases served satisfactorily in low dams, it has not done so in the higher dams, and that the best material to use is a mixture of gumbo or other clayey material and gritty material in the proportion of one part of clayey material to two or three parts of gritty material. Material that melts easily when in contact with water, or that contains an appreciable amount of soluble salts, should be rejected, unless absolutely unavoidable, in which case the dam should be safeguarded against danger from this source by enlarging the cross section and encasing it with a covering of selected material well packed. No detritus, sod, or other organic material should enter the dam. Material should always be damp when put in place, its consistency being such as to readily pack hard with tramping of horses. Dry material should never be used, and care should be exercised not to get it too wet or slushy. Material may be dampened by the addition of water from a ditch or stream, as it is put in place. If this is not available, advantage should be taken of the rainy season, so that the material in the borrow pits may be kept damp from rains. By stripping the sod over the borrow pits and wasteway and then plowing them some time before construction begins, rains will soak into the plowed ground and give a large quantity of damp earth for the dam. By repeating this operation, damp earth may be obtained for the entire structure. There is no good reason why this method should not be adopted, as a man contemplating construction should have his plans matured sufficiently in advance to take advantage of opportunities of this sort. During the spring the rains are frequent enough to involve little or no delay. In constructing reservoirs of this class packing is practiced only by the tramping of animals, though there is no reason why the four-horse Fresno scraper should not be used in place of the two-horse slip scraper, for, by using care in distributing the material in thin sheets, it becomes just as well packed by using the larger scraper. With an increase of only one-third the expense, four or five times the amount of work can be done with a Fresno as with a slip scraper. It will be found economical to make the borrow pits not more than 4 feet deep in any case and more often not greater than 3 feet. No material should be borrowed from below the dam, as this practice leads to the collection of seepage and storm waters which become a menace to the safety of the structure. When borrowed

inside the dam, a berm should be left whose width is eight times the depth of the borrow pit, with a minimum of 20 feet. In building an earthen dam, allowance for settlement should not be forgotten. If the embankment is not puddled, it is customary to increase the dimensions of the dam 10 per cent over those desired after settlement.

The foundation for the dam should be firm ground. Soft or marshy ground should be carefully avoided, as the cost of properly preparing it to receive the dam would be prohibitive in a work of this size, and without other preparations the dam is liable to fail and the leakage will be great. All sod and perishable material should be removed over the entire area of the foundation, for if these are allowed to remain they will in time disintegrate, and minute channels will be formed beneath the dam, which the water will lose no time in following. This will result in leakage under the dam, or the dam itself will become saturated. Either is an undesirable condition and will eventually cause greater damage. It is therefore necessary to get the best possible bond between the dam and its foundation, to secure which after the sod is removed the surface should be thoroughly plowed at least 6 inches deep. When the height of the dam is greater than 10 feet, it is desirable to introduce an intercepting trench running along the foundation for the whole length of the dam. The trench should be about 2 feet deep and 10 to 15 feet wide and be located just in advance of the crest of the dam. This will act as a safety factor in interrupting any possible seam that may occur at the base of the dam. The surface of the intercepting trench should be plowed or cultivated before being filled in, so that a good bond is obtained between the surface of the trench and the superimposed earth.

The cross section of the dam depends upon its height and the material used. With fairly good material experience shows that the upstream side of the dam should have a slope not steeper than 1 on 3 while the rear slope may be as steep as 1 on 1½, though 1 on 2 is preferable. The top width should vary with the height, that for a dam less than 10 feet high being 6 feet, for a dam from 10 to 15 feet high 8 feet, and for a dam from 15 to 20 feet high, 10 feet.

Outlet.—The outlet should be of such size as to supply enough water when completely open to comfortably fill the irrigation ditch. The loss of water in a ditch is much less per irrigation when running a good head of water than when running a small amount, for which reason the outlet should rather be too large than too small. In calculating the capacity of the outlet, it must be borne in mind that this varies largely with the elevation of the surface of the water in the reservoir. From this investigation it would appear that 6 inches to 8 inches diameter are the favorites.

Four kinds of outlets are available, viz, wooden box, wrought iron, cast iron, and earthenware pipe. The wooden box is a makeshift and should never be used, because its life is short and when rotten is very difficult and expensive to replace and if allowed to decay will be instrumental in breaching the dam. Wrought-iron pipe is used to a large extent. It is strong, flexible, water-tight, and will last ordinarily 25 or 30 years in the ground. Earthen dams, however, if well constructed are supposed to last forever, so that in common therewith it would seem that a more lasting outlet should be used. Cast iron will probably last from 50 to 100 years, but is expensive and difficult to lay well. Being less flexible than wrought iron, it will not adjust itself readily to settlement that may occur in the dam. Earthenware pipe, if vitrified and salt-glazed and double strength, is perhaps as everlasting as the earthen dam itself. It has the objection of being made in short lengths, and therefore having very many joints which are difficult to make and keep water-tight when the pipe is operating under a head. In case of sewers, however, it is not uncommon for the pipe to be under a head of 10 feet, and in many cases the leakage has been practically nothing. This is particularly true where sulphur has been substituted for cement in making the joints. Three parts of sand to one part of sulphur are mixed and heated to fluidity, the joint being made by pouring the mixture into a mold around the joint. Earthenware pipe is practically inflexible and can not adjust itself to conform with settlement in the embankment without breaking either the joints or the pipe, or both, so that a very firm bed for the pipe is essential. Earthen pipes are also subject to longitudinal cracks from heavy or eccentric loading of the superimposed embankment. In choosing between iron pipe and earthen pipe, the advantage and disadvantage of each must be considered in connection with the local conditions of the outlet.

In the smaller sized outlets, the ordinary gate valves are customarily used; but when the size of the outlet is in excess of 10 inches, a specially constructed brass-lined sliding gate proves more efficient.

With iron pipes, the valve or gate may be either above or below the dam, though it is deemed better practice to have it above the dam. With an earthenware pipe it is essential that the valve or gate be at the upper end, for it would not do to have the joints subject to a hydrostatic head continuously. If the valve is placed at the upper end of the outlet, a footbridge is necessary from which it may be operated. It should be seen that the stem is large enough to withstand the tortional stress created when the valve is started and is held securely in place by guides. As there are no logs or other floating bodies to contend with on the prairies, it is not necessary to have protection of any consequence for the upper end of the *outlet.*

The outlet should be laid in a trench excavated in solid ground, and should be sufficiently above the lowest part of the reservoir to be free from silt. If the dam be over 15 feet high, cut-off walls or collars should be placed around the pipe at intervals of 10 or 12 feet. These should be masonry, as planks will rot and create serious trouble. They need be only thin slabs and should extend 2 feet all around the pipe. Their office is to interrupt seepage along the surface of the outlet. Whether or not any cut-off walls are used, the trench after receiving the pipe should be carefully filled and tamped.

Protection of slope.—Ordinarily the material available for earthen dams on the prairies is more or less easily affected by water, and, when not subject to the action of waves, the inner slope of the dam should receive an outer coating of firmer material, such as an artificial mixture of gumbo or clayey material and gravel or grit in the proportion of 1 to 2. This covering should have a thickness of at least 12 inches and progress simultaneously with the other part of the dam, being well bonded to it. The rear slope is subject to the cutting action of rains and snow, but is best protected by a sod. Where the water slope is subject to the action of waves, the covering above noted will not be sufficient protection. The best protection is pitching composed of hard rocks weighing about 100 pounds each and bedded on a layer of gravel or broken stones varying from screenings to 2 inches in largest dimension. The underlying layer of gravel or broken stones is essential, for, were the pitching bedded directly on the earth, the waves would dash into the joints between the individual rocks and upon receding would carry out some of the underlying earth. Constant action of this sort will soon remove the support of one or more of the rocks, they will become displaced, and the continuity of the pitching will be interrupted. After this the waves make short work of the entire protection. If pitching be used, care must be taken to have the individual rocks fit snugly together and to have the joints as small as possible. All cusps or spaces due to irregularity of the rocks should be filled with spalls.

If the work be of sufficient importance and the proximity to market permit, reenforced concrete or cement concrete blocks may be substituted for stone pitching, though under ordinary conditions stone pitching is the least expensive. If reenforced concrete be used, the embankment should be allowed to settle well before the concrete is laid. The metal to be used for reenforcement should be comparatively heavy bars in order to longer resist corrosion, for it must be remembered that concrete is porous, and there is no reason to believe that iron or steel will not rust when embedded in concrete as it does in air or in the ground, though at a slower rate. Thin plates whether meshed or solid would rust away much sooner than would heavy bars, at which time reinforcement would cease. When

within a few miles of market, at current prices reenforced concrete and cement concrete blocks would both cost in the neighborhood of 20 cents per square foot, while pitching with good rock handy would cost but 11 cents per square foot. The reenforced concrete would be either a monolith or in large slabs. It would have the advantage of presenting a solid smooth face to the waves and the disadvantage of cracking in case of settlement in the embankment. The cracks, however, could be easily closed with cement mortar or grout. Ordinarily, there are gravel pits available throughout the prairie which may be used for the concrete, in the proportion of 1 cubic foot of Portland cement to 5 cubic feet of gravel. With this proportion it will ordinarily take 1 barrel or 375 pounds of cement per cubic yard of concrete. In most cases in the prairies the cost of either pitching, reenforced concrete, or cement concrete blocks is prohibitive, and other less permanent materials must be employed for wave protection.

The wave fence used by the Chicago and Northwestern Railway has not proved altogether satisfactory. In the first place, its life is short. In the second place, while it decreases, it does not entirely prevent, wave wash. The reason for this is that the receding water gradually drags back the material from directly in front of the fence until the points of the boards become exposed to the water, which then dashes in between them and begins to wash out the slope behind them. It is also hard to drive the boards so close together as to prevent water passing between them. The fence would behave better if a double thickness of boards were used, lapping joints, and if they were driven about 2 feet deeper into the slope. But, at best, the fence is a temporary structure, which, for that matter, is true of all others save those above described. The brush protection used by Mr. Harris (page 44) has served fairly well, and by being used to a greater extent on the slope may prove satisfactory though temporary.

In a small reservoir near Cheyenne where wave action was bad, a layer of old railroad ties was laid up vertically for a height of 5 feet above the slope, being held in place by other ties driven into the slope. The space above the ties was filled in with earth, which afforded the ties stability against the force of the waves. The ties formed a sort of revetment, with their bottom somewhat below high water. On the slope inside the reservoir riprap was deposited to prevent receding waters from undermining the ties. This has been in operation for several years and shows no signs of failure yet. A view of this revetment is shown in Plate VIII, figure 2. It is not often, however, that old railroad ties are available, for many of the reservoirs are a long way from the railroad, and the cost of other large timbers is prohibitive because of their scarcity.

WASTEWAY.

The wasteway has probably been the cause of more damage to reservoirs than any other one element. This is because the wasteway does not receive proper consideration, it being commonly either poorly located, poorly protected, or too small. If the topography will permit, the wasteway should be located some distance away from the dam, so that waste waters, however great, may not come in contact with its slope nor in case of excessive erosion endanger the dam. A gap or saddle in the hills that form the walls of the reservoir is sometimes available for this purpose. When the topography is such that the wasteway may not be located entirely apart from the dam, as where the walls rise precipitously on all sides, it must be constructed around one or both ends of the dam. This may be done either by excavating a trench sufficiently large to carry the waste water or by building the dam high enough to form a wasteway of the natural ground. It has been the experience in the prairie region that ground once disturbed erodes very easily, while if the sod be allowed to remain the waste water may attain quite high velocities without doing damage. In the latter case it becomes necessary to reenforce the end of the dam next to the wasteway by means of a levee running parallel with the wasteway and extending upward and downward past the toes of the slopes so that the waste water may not come in contact with the dam. If the water be allowed to come in contact with it, the dam will be endangered by either washing or saturation, or both. The top of the levee should be 6 feet wide and level with the top of the dam. On the waste-way side the slope of the levee should not be steeper than 1 on 3, and if possible should be riprapped or otherwise protected from wash. The slope of the dam side may be the angle of repose assumed by the material used, and needs no special protection. The levee should be constructed as carefully as the dam itself, for upon its stability rests the security of the dam. That portion of the wasteway lying upstream from the lower edge of the crest of the dam should be very nearly level.

In nearly all wasteways the water drops rapidly in a short distance before it reenters the stream. Wherever this is the case, erosion to an astonishing degree will soon take place. Most of the fall is taken up in one vertical drop, creating a great gulch below it. With successive discharges of waste water this vertical fall rapidly recedes, and if allowed to reach the reservoir will destroy its usefulness. It is essential, then, that measures be taken to prevent this erosion, which may be done either by paving the bottom of that part of the wasteway having great fall or by constructing one or a series of checks at each of which a fall is created, the object of the check structure being to prevent the fall from receding. Another way is to

construct a chute similar to that described in discussing the Kidd Reservoir (page 57). Whatever method is used, care should be taken, by means of aprons and wings, to prevent the water from passing under or around the structure or from washing out its foundation where the water drops below it. Either masonry, timber, or brush may be used with which to make the checks, though if brush is used it is best to make a series of checks, creating a number of small falls or a rapid. It must be remembered that structures of either timber or brush are only temporary and in need of constant inspection and repair. Material refilled around structures should be well tamped, water being used where possible.

There seems to have been an inclination on the part of reservoir builders in the territory investigated to have the difference in elevation between the top of the dam and the bottom of the wasteway too small, this oftentimes being not more than 2 feet. The depth of wasteway to be used depends upon the area and shape of the water surface, the direction of the prevailing wind, and the degree to which the reservoir is sheltered. Under the most favorable circumstances it should not be less than 4 feet, and when the dam is subject to the action of waves from the prevailing winds and the area of the reservoir is over 50 acres and within the scope of this work, it should be 6 feet. The wasteway of the East Cottonwood Reservoir of the Chicago and Northwestern Railway has a depth of 5 feet, while the area of the reservoir is something over 50 acres. Settlers in that neighborhood assert that they have seen waves in a heavy wind strike the top of the wave fence, a portion of the wave being stopped and the remainder clearing the top of the dam and striking on its lower slope. Indications confirm these statements.

This depth of the wasteway is not for the purpose of carrying great depth of water but to protect the dam from the waves with the reservoir full and wasting. The depth of water in the wasteway should be kept as small as possible, and the width should be such that this depth to carry the calculated waste flow will be not greater than 2 feet and preferably 1 foot, for a wide shallow sheet of water does not have the erosive power that the same quantity of water with less width and greater depth has. The size of the wasteway necessary has already been discussed on pages 32–35, to which reference should be made.

SILT.

In certain portions of the prairies the accumulation of silt detracts considerably from the usefulness of a reservoir and eventually reduces the storage capacity to practically nothing, as was pointed out in discussing some of the Chicago and Northwestern Railway reservoirs. One can usually tell from the character of the tributary catchment area whether there will be much silt to contend with. *Those most productive* of silt show signs of erosion, the gumbo and

shale leading in this regard. If a catchment area has a smooth appearance and is well covered with sod, there will not as a rule be a dangerous amount of silt. The only way to prevent the collection of silt in a reservoir is to construct another reservoir above the one to be used for storage, the former to serve as a settling basin. This is not usually practical because of the expense, and then with each succeeding year the efficiency of the settling basin decreases and it will not take many years to fill with silt and become not only useless but a menace to the lower reservoir.

The accumulation of silt may be avoided by locating the reservoir away from the supplying catchment area, transporting the water to the one from the other by means of a supply ditch. The reservoir should thus have a very small catchment area above it. Because the velocity of the water is greatly reduced in entering the supply ditch, the silt is deposited near its head and may be removed with scrapers when the ditch is not in use. If it is not possible to locate the reservoir independent of the catchment area supplying the water, the silt deposit may be reduced to a minimum by proportioning the capacity of the reservoir and the size of the catchment area so that the reservoir will be filled but once during a year, for the depth of deposit will vary directly as the number of times the reservoir is filled; that is, under the same conditions the depth of silt deposited per year in a reservoir furnished with sufficient water to fill ten times annually will be ten times the depth of deposit per year in a reservoir which is furnished only sufficient water to fill it once.

When the deposit of silt has reached a point where the reservoir becomes useless, it is cheaper to build a new reservoir than to remove the silt. Take for example the four reservoirs abandoned by the Chicago and Northwestern Railway because of silt. To remove the silt will cost from 15 cents to 20 cents per cubic yard, according to local conditions and size of reservoir. Taking the lower figures the cost of moving 1 acre-foot of silt will be:

$$\frac{43{,}560}{27} \times 0.15 = \$242.00$$

We have then:

Cost of removing silt.

Reservoir.	Silt.	Cost of removing.	Original cost of reservoir.
	Acre-feet.		
Montgomery	38	$9,196	$545.26
Battle Creek	85	20,570	712.25
Bull Creek	27	6,534	657.75
Indian Springs	19	4,598	407.68

From this table it is seen that the cost of removing silt would be from 10 to 30 times the original cost of the reservoir and is therefore prohibitive. In some cases it may be possible to add to the height of the dam, though this is nearly always impracticable because of the

difficulty in obtaining new wasteway and the height the dam gets to be, for with the higher dam conditions arise that were not provided for in first construction, which makes the security of the higher dam a grave question. Again, the higher dam needs more careful and elaborate work all through, and when finally done will cost more than it would have cost to duplicate the original dam, and at best it will not be altogether satisfactory.

SEEPAGE LOSS.

In new reservoirs, particularly when fed by a supply stream carrying no silt, loss by seepage is often a very serious matter. In reservoirs constructed in the stream bed of the tributary catchment area, the seepage losses are generally checked to a large extent after the first flood, for the water impounded always carries at least a small percentage of sediment which settles when the water becomes stationary, covering the floor of the reservoir with a thin layer of silt. The silt is composed of very finely divided particles which are forced into the pores of the soil, making it less porous. With successive deposits the reservoir becomes practically water-tight, the loss from seepage being usually less than that from evaporation. A small amount of silt in the water is, therefore, desirable. For reservoirs not in the stream bed of the tributary area, it is necessary to do artificially what in the other case is done by nature. This may be done by harrowing the surface of the reservoir thoroughly, turning in the water and tramping with animals. For this purpose it is best to use hogs or sheep, as their hoofs are smaller and they are less likely to mire than cattle. It is not sufficient to drive the animals through a few times, but they must remain there for some days. Hogs are the best to use, for they will wallow and root and lie down in the mud. They keep the surface constantly stirred, pack the soil beneath, and a thin layer of silt will form on top, filling the pores of the soil beneath. If penned and fed in the reservoir, they will in a season have the reservoir practically water-tight and be a good commercial investment for the owner. That the use of animals in this way is effective is shown by the fact that buffalo wallows are uniformly impervious to water, there having been created a thin coating of well packed, finely divided particles. If this coating or crust be broken through, the wallow loses its impervious qualities. On the small reservoir at the Cheyenne experiment farm, leakage was at first very great because the soil was coarse and gravelly. Eighteen inches depth of water disappeared by seepage and evaporation in three days. The surface of the reservoir was harrowed, the water turned in, and the bottom thoroughly stirred and tramped by men with rubber boots. After four treatments of this sort, each lasting a whole day, the leakage was reduced to one-fifth inch per day.

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CIRCULARS.

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